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Watercraft Waste Treatment System Development and Demonstration Report

135

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A shipboard sewage treatment system consisting of: 1) comminution of solids for ease of transport and further treatment; 2) Electro coagulation of sewage for ease of removal of suspended solids; 3) solids separation; 4) soluble BOD reduction with carbon adsorption; 5) coliform bacteria removal; and 6) solids incineration was designed to process shipboard sanitary, culinary, and laundry wastes during prolonged sea trials. Advantages of the electrochemical system include: 1) less vulnerability to hydraulic and chemical shock loads; 2) lesser physical size and weight than biological systems; 3) ease of automation; and 4) the treatment processes can be rapidly started and stopped. Waste stream characterization showed the BOD and suspended solids levels of shipboard wastes to be 2 to 3 times the concentrations common to municipal wastes. Shipboard wastes effluent from the demonstration plant contained essentially zero coliforms, 94 mg/l BOD, and 49 mg/l suspended solids, all below the 240 MPN/100mg, 100 mg/l, and 150 mg/l standards for coliforms, BOD and SS respectively. The development program was successful in demonstrating a practical and economically viable electro-chemical treatment system, and further refinements are continually being explored. (Lowry-Texas)

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Texas Univ, Austin

WATERCRAFT WASTE TREATMENT SYSTEM

DEVELOPMENT AND DEMONSTRATION REPORT

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this document may be better
studied on microfiche

BY

GENERAL ELECTRIC COMPANY
RE-ENTRY AND ENVIRONMENTAL SYSTEMS DIVISION
PHILADELPHIA, PENNSYLVANIA 19101

FOR THE

ENVIRONMENTAL PROTECTION AGENCY

PROGRAM 15020 DHG

SEPTEMBER 1971

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This report has been reviewed by the Office of Research and Monitoring, Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

A demonstration program of electro-chemical processing of shipboard sanitary, culinary, and laundry wastes including prolonged sea trials on board a large vessel was conducted. Extensive analytical results are presented demonstrating ability to produce effluent of secondary water quality standard and to incinerate system by-products. Substantial data for the design of shipboard systems is also presented.

The economic viability of the treatment system developed is analyzed and compared with alternative approaches with the conclusion that dependence of large vessels on shore side facilities in conjunction with on-board holding equipment is eliminated in many cases.

The program demonstrates the unique character of shipboard wastes and the shipboard environment verifying the need for specially developed equipment for treatment such as the system demonstrated.

The program suggests further extension of the capabilities of the system developed for increase in capacity and for elimination of other ships wastes such as bilge water and wet and dry garbage.

This report was submitted in fulfillment of Contract Number 14-12-522 under the sponsorship of the Office of Research and Monitoring, Environmental Protection Agency.

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SECTION I

CONCLUSIONS

1. As a result of the Watercraft Waste Treatment System Development Program a practical and economically viable electro-chemical treatment system has been demonstrated.

2. The system meets or exceeds the effluent water quality standards proposed by the Environmental Protection Agency on May 12, 1971 (Federal Register, Volume 36, No. 92).

Proposed Standard	Demonstration Result
Coliform bacteria less than 240 MPN Col./100 ml	Essentially zero colonies
Biochemical Oxygen Demand Less Than 100 mg/1	Average 94 mg/1
Suspended Solids Less Than 150 mg/1	Average 49 mg/1

3. Water treatment by products, such as sludge, can be safely and economically incinerated on board ship.

4. Shipboard sewage (culinary, sanitary and laundry wastes) contain significantly higher Biochemical Oxygen Demand and suspended solids than commonly encountered in municipal waste. A factor of two or three for Biochemical Oxygen Demand and Suspended Solids over municipal wastes should be utilized for system design. The ratio of dissolved Biochemical Oxygen Demand to total Biochemical Oxygen Demand is significantly higher for shipboard wastes than municipal wastes.

5. Enforcement of water quality standards and other State and Federal Regulations will result in increased sewage Biochemical Oxygen Demand and suspended solids on board ship as housekeeping habits are improved.

6. Present techniques for on-shore evaluation of treatment plants are of limited value due to the difficulty in accurately reproducing hydraulic, chemical and biological loading of a system.

7. Biochemical analysis of shipboard wastes is highly sensitive to technique; the wastes are significantly different from those of a municipal nature. The Standard Methods must be rigorously adhered to. Erroneous technique for Biochemical Oxygen Demand determination will usually result in analytical results indicating lower than actual values and mislead performance evaluation.

SECTION II

RECOMMENDATIONS

1. Continue system development for elimination of other shipboard wastes such as bilge water, wet garbage and dry combustibles. The system has unique potential for handling these wastes with minor modifications.

2. Continue evaluation of means for removal of dissolved Biochemical Oxygen Demand for the purpose of improving operating economics.

3. Increase system reliability by elimination of the solids concentrator and increasing the size of the upflow clarifier.

4. Increase system capacity by development of a reliable, inexpensive, sludge level detector.

5. Develop a rigorous certification program for shipboard waste treatment systems. Land-based demonstration should be accompanied by a carefully programmed simulation of shipboard sewage loading.

6. Develop a certification program for analysis of shipboard effluents thus insuring an equitable comparison of competitive treatment systems.

7. The burden on shipboard waste treatment facilities may be reduced by minimizing hydraulic loading (careful adjustment of heads and other water sources) and providing convenient receptacles for paints, solvents, descalers and other chemicals commonly used on board ship.

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SECTION III

INTRODUCTION

A. Statement of Problem

The Report of the Department of the Interior, FWPCA, to the 90th Congress entitled, "Wastes from Watercraft" contains a compelling assessment of the magnitude of water pollution of the Nation's waterways. In view of the Nation's new resolve to restore and enhance the quality of our water, it was stated that vessel discharges could not be ignored. It made little sense to expect cities and industries to clean up discharges only to have the water remain polluted by discharges from vessels. Harbors, bays, lakes, estuaries, and other heavily navigated waters differ in their physical and hydrological characteristics and also from the pollution control standpoint. Because of differences in assimilation capacity, vessel pollution may assume critical proportions in some areas.

Prior to the start of the program described herein there was considerable doubt among the marine engineering and naval architectural communities about the feasibility and practicality of on-board treatment of watercraft wastes. The lack of availability of suitable on-board treatment facilities left the marine engineer with only one choice for disposal of wastes; on-board storage with subsequent discharge on shore or at sea. On-board storage is a simple solution in some cases but raises manifold problems in many others. Primary are the problems of adequate space on board ship for storage and the lack of suitable shore facilities for transfer and treatment of watercraft wastes. In the case of ships operating from small ports, many municipalities have found themselves incapable of handling the ship wastes; the wastes being equivalent to the total daily treatment capacity of a small community.

Many of the problems associated with on-board treatment versus holding are intangible and particularly difficult to assess economically. Such factors as vessel delays in port, inconveniences associated with waste transfer, and the need for additional personnel are worth money, but how much? Complete independence from shore is obviously desirable and circumvents many of the intangibles. This was the prime motivator behind the work achieved in this program.

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B. Objectives

The objectives of the watercraft waste treatment program were:

1. Develop a prototype shipboard waste treatment system.
2. Demonstrate ability of the shipboard waste treatment system to produce effluent of secondary water quality standard during sea trials on board a representative vessel.
3. Demonstrate feasibility of incineration of sludge produced by the plant thereby demonstrating proper treatment and disposal of all plant effluents.
4. Evaluate the economic viability of the system developed.

C. Technical Approach and System Description

The method chosen for treatment of shipboard wastes was electrochemical in nature as contrasted to the more classical biological techniques commonly used for land-based treatment of municipal wastes. This choice was based on the following factors which were later demonstrated to be essentially correct.

1. Electrochemical treatment, which does not rely on formation of a stable bio-mass for sewage processing, is less vulnerable to hydraulic and chemical shock loads which are likely to occur on a ship. Ability to process with variable salinity of the carrier water is particularly important.
2. Electrochemical treatment facilities are inherently smaller and of less weight, due to shorter sewaage processing times, than equivalent biological treatment facilities. These characteristics are desirable due to limited space and weight available on shipboard.
3. Electrochemical treatment processes lend themselves readily to automation thus precluding the requirement for specially trained personnel on board ship for maintenance of the treatment facility.
4. Electrochemical treatment processes can be rapidly started and stopped.

The process selected for development and demonstration involves six discrete steps:

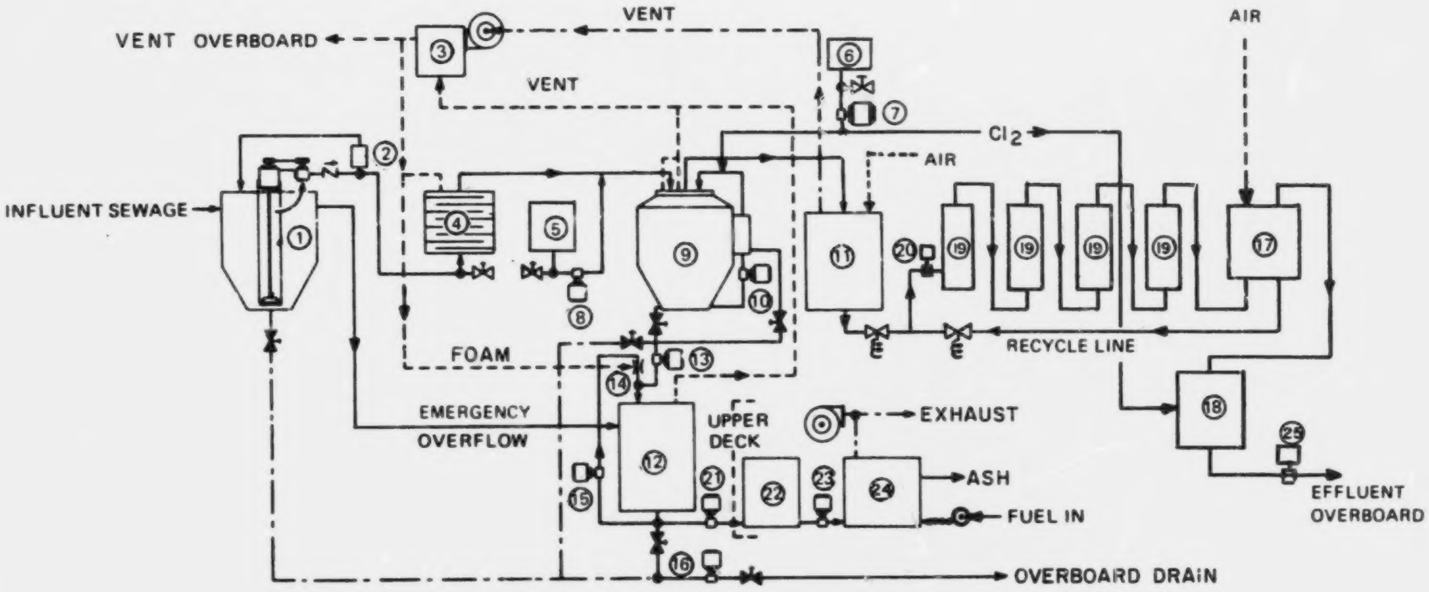
1. Comminution of solids for ease of transport and further treatment.
2. Electrocoagulation of sewage for ease of removal of suspended solids.
3. Solids separation.
4. Soluble BOD reduction.
5. Coliform bacteria removal.
6. Incineration of solids.

To implement the process steps delineated in the technical approach, a system as shown in Figure 1 and described in Table 1 was developed. A description of the system inclusive of key operating principles is included herein because of the extent of wholly contractor-developed hardware involved.

The treatment plant is located at a suitable deck location for collection of the combined wastes generated aboard the ship. The total wastewaters of sanitary, culinary, laundry and wash origin are collected in the receiving tank of the pump-grinder, the primary functions of which are comminution of solids and establishment of the process flow rates. Sufficient volume is incorporated in the receiving tank to optimize system processing duty cycles.

The solids content of the waste water is comminuted by the grinder to particles of cross section not exceeding 0.25 inch diameter. The resulting slurry is pumped at a rate of 5 gallons per minute to the electrocoagulation cell for coagulation. Electrical generation of the coagulating agent by applying direct-current voltage to iron containing plates was employed. Iron was selected over aluminum as the expendable metal ion source because of superior settling characteristics of the agglomerated iron flocculent particles.

Flocculation of the "micro floc" formed within the electrocoagulation cell is accomplished by rotating motion enhanced by addition of sodium aluminate as a flocculant aid. The mixing is an initial function within the downcomer section of the upflow clarifier. Subsequent detention at a suitable rate of flow upwards through the clarifier permits the formation of a layer of sludge (sludge blanket) comprised of the flocculated sewage solids. The clarified water overflows a weir at the top of the clarifier. Unlimited growth of the sludge blanket is precluded by programmed sludge withdrawal from the blanket. Maintenance of


VENT OVERBOARD
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INFLUENT SEWAGE
FOAM
EMERGENCY OVERFLOW
UPPER DECK
RECYCLE LINE
EXHAUST
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1. Pump Grinder
2. Relief Valve
3. Blower and Venturi
4. Electrocoagulation Cell
5. Flocculant Aid Storage
6. Hypochlorite Storage
7. Hypochlorite Pump
8. Flocculant Aid Pump
9. Upflow Clarifier and Concentrator
10. Sludge Recycle Pump
11. Effluent Holding Tank
12. Sludge Storage Tank
13. Sludge Withdrawal Pump
14. Foam Extractor
15. Foam Recycle Pump
16. Emergency Drain Pump
17. Effluent Aeration Tank
18. Chlorination Tank
19. Carbon Columns
20. Effluent Recycle Pump
21. Sludge Transfer Pump
22. Sludge Day Tank
23. Sludge Pump
24. Incinerator
25. Overboard Discharge Pump

Figure 1. Watercraft Waste Treatment System Schematic

TABLE 1. WATERCRAFT WASTE TREATMENT SYSTEM OPERATING AND DESIGN PARAMETERS

Volumes

Pump Grinder Receiving Tank - 150 gallons
Upflow Clarifier - 300 gallons
Chlorination Tank - 100 gallons
Sludge Concentrator - 110 gallons
Sludge Holding Tank - 100 gallons
Floc Aid Storage - 30 gallons
Hypochlorite Storage - 30 gallons
Electrocoagulation Cell - 10 gallons
Carbon Columns - 30 gallons ea. (4) (70 lbs. carbon ea.)
Aeration Tank - 30 gallons

Flows

Pump Grinder - 5 gpm
Clarifier Recycle - 4 gpm
Sludge Withdrawal - 3 gpm
Sludge Recycle - 11 gpm
Sludge Transfer - 11 gpm
Overboard Discharge - 8 gpm
Emergency Drain Pump - 53 gpm
Floc Aid - 12 ml/min
Hypochlorite - 7ml/min
Carbon Column - 4.6 gpm
Incinerator Feed - .33 gpm

high quality effluent is assured when the sludge solids content falls within the limits determined by a balance of influent and effluent solids. The withdrawn sludge is stored within a holding tank for disposal by incineration.

The incinerator is specially designed to incinerate "wet" sludge to yield inert ash and harmless gaseous effluents.

Soluble BOD is removed from the clarifier effluent by passing the effluent through continuously aerated activated carbon columns. Continuous aeration is assured by aerating column effluent and recycling it through the columns when no upflow clarifier effluent is available. The effluent is disinfected by chlorination for discharge overboard.

Two auxiliary functions contributing to effective and safe operation are performed by the hydrogen vent blower and foam extractor. Hydrogen generated by electrolysis of the waste water is safely diluted and discharged by the vent blower. Foam which is generated in sizeable quantities when treating sanitary wastes is removed by the foam extractor for incineration. The solids yield from foam extraction is significant.

D. Program Plan

Contract 14-12-522 entitled Treatment of Watercraft Wastes was awarded January 1969 and work was initiated May 1969. The contract was divided into two phases. The key objective of Phase I was a laboratory demonstration of a system to treat combined vessel wastewaters to secondary water quality standards, while the key objective of Phase II was a demonstration of this equipment aboard a representative vessel for an extended period.

A Program plan was prepared which included the following tasks during Phase I:

1. Component design, development and test; stressing electrocoagulation and solids separation.
2. Selection of suitable ship for Phase II demonstration.
3. Survey of wastewater characteristics aboard the selected ship.
4. Motion simulation test of motion sensitive components.
5. Design of controls, power supply, sensors, pumps and tanks to incorporate development components into the treatment system.

6. Test system in a shore-based laboratory.

7. Refurbish for installation in demonstration ship.

Phase II, included the following tasks:

1. Installation of the system aboard the ship.

2. Demonstration of the system aboard ship.

3. Extensive laboratory analysis during sea trials.

4. Installation of sludge incinerator.

5. Economic analysis.

6. Final report.

SECTION IV

SYSTEM DEVELOPMENT

A. Summary

The waste treatment system developed for this program was evolved from the basic technology of electrocoagulation in early 1969 through development of the essential elements necessary for automated processing of sewage on board a ship. The selection of the test vessel, the Gerig, in July of 1969 and subsequent survey of the vessel's hydraulic and biochemical loading permitted final sizing and design of the shipboard developmental system. Key portions of the system were then evaluated in the laboratory at the subsystem level prior to assembly and test as a complete system. During the spring and summer of 1970, the completed system was evaluated in the laboratory utilizing sanitary sewage produced by a large office building augmented by various mixtures of simulated sewage, culinary wastes, and actual wastes obtained from the U.S. Coast Guard Cutter Sassafras.

In August 1970 the system was prepared for shipment to the Gerig. The system, at this time, did not include a sludge incinerator. When the program was initiated it was thought that an incinerator suitable for shipboard use could be procured on the market and, as a consequence, did not require demonstration during this program. Subsequent evaluation of some 70 incinerator manufacturers in the United States indicated that a small, light weight, automatic incinerator suitable for shipboard use was available from only one vendor. An early and much used model of this incinerator was obtained for evaluation in May 1970. This incinerator was found to be incompatible with the prototype system.

Because disposal of sludge is a necessary adjunct to sewage treatment and an incinerator can be utilized for other wastes on board ships, General Electric developed an advanced incinerator design for inclusion in the demonstration program. This incinerator was installed on the Gerig in January 1971.

The waste treatment system was installed on the Gerig during the period of Sept. 1970 to Oct. 1970. Systems tests commenced Dec. 16, 1970. Some limited performance data had been obtained in late October while the Gerig was in dry dock and the vessel was hooked up to a fresh water supply.

During the sea trials the Gerig operated from a number of ports, listed in Table 2, on the Gulf and Atlantic coasts until August 1971. The operation of the system during sea trials is covered in detail in Sections IV and V.

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Operation on board the Gerig offered a unique opportunity for thorough evaluation of shipboard waste treatment problems. The various ports of operation provided background water of varying salinity, temperature, dissolved oxygen content, and solids concentration; in fact some of this water was badly polluted. The ship provided a ship-to-shore launch twice a day as part of its normal routine thereby facilitating transport of fresh samples to laboratories for biochemical analysis. During part of the sea trials, an Environmental Protection Agency mobile water analysis laboratory was based at the dock for immediate analysis of water samples.

TABLE 2. GERIG PORTS DURING WATERCRAFT WASTE TREATMENT SYSTEM SEA TRIALS

Place	Date
Tampa, Florida (Dry Dock)	September 1970 to December 18, 1970
Pascagoula, Mississippi	December 19, 1970 to January 1, 1971
Gulf Port, Mississippi	January 2, 1971 to January 14, 1971
Pensacola, Florida	January 15, 1971 to January 23, 1971
In Transit	January 24, 1971 to January 25, 1971
Port Canaveral, Florida	January 26, 1971 to February 9, 1971
Savannah, Georgia	February 9, 1971 to March 10, 1971
Brunswick, Georgia	March 11, to April 10, 1971
In Transit	April 11, 1971 to April 13, 1971
Boca Grande, Florida	April 14, 1971 to April 21, 1971
In Transit	April 22, 1971 to April 24, 1971
Wilmington, North Carolina	April 25, 1971 to July 2, 1971
Moorehead City, North Carolina	July 3, 1971 to August 9, 1971

In July and August 1971, General Electric provided shore laboratory facilities within a few miles of the dock. When the ship was at a port for short periods, certified commercial laboratories were utilized.

B. Vessel Selection

Vessel selection for the demonstration of the watercraft waste treatment was the result of a cooperative effort involving the Environmental Protection Agency, the Army Corps of Engineers, the Coast Guard, and the General Electric Company. Selection required a trade-off study considering geographic area of operation, crew size, operating schedule, existing sewage plumbing, and availability for modification.

Utilization of a Coast Guard vessel was eliminated early in the trade-off as Coast Guard activities result in an unpredictable operating schedule which would adversely affect test sample collection.

Review of U.S. Army Corps of Engineers Hopper Dredges serving the East Coast indicated that the Dredges Gerig and Goethals would be acceptable choices. Both vessels operate in reasonable proximity to the Philadelphia area, crew size to be served by the waste treatment system (about 50 men) is ideal, and the operating schedules are predictable.

The Gerig, shown in Figure 2, was selected for sea trials. Operations of the Gerig are typical of an ocean going vessel; activities are conducted 24 hours a day, seven says a week. The Gerig is continually under way with substantial operating time spent several miles off shore. The Gerig dredging schedule results in exposure to different background water conditions associated with the various ports and at sea conditions during transit time of several days duration. The Gerig was therefore both a convenient test bed and is typical of vessels for which the watercraft waste treatment system was developed.

The design work necessary for the installation of the waste treatment system was accomplished in conjunction with the U.S. Army Corps of Engineers Marine Design Division located in Philadelphia.

The waste treatment system was installed on the Gerig during October 1971 at the Tampa Shipyard. The unit was installed on the aft lower deck on the port side in the crew's locker room. The unit was plumbed in parallel with an existing treatment system. The plumbing was arranged to allow flow of sanitary, shower, galley, and laundry waste to the system. The general arrangement is defined on Corps of Engineers, Philadelphia, office drawing 1-10-104. The incinerator was installed on the top boat deck.

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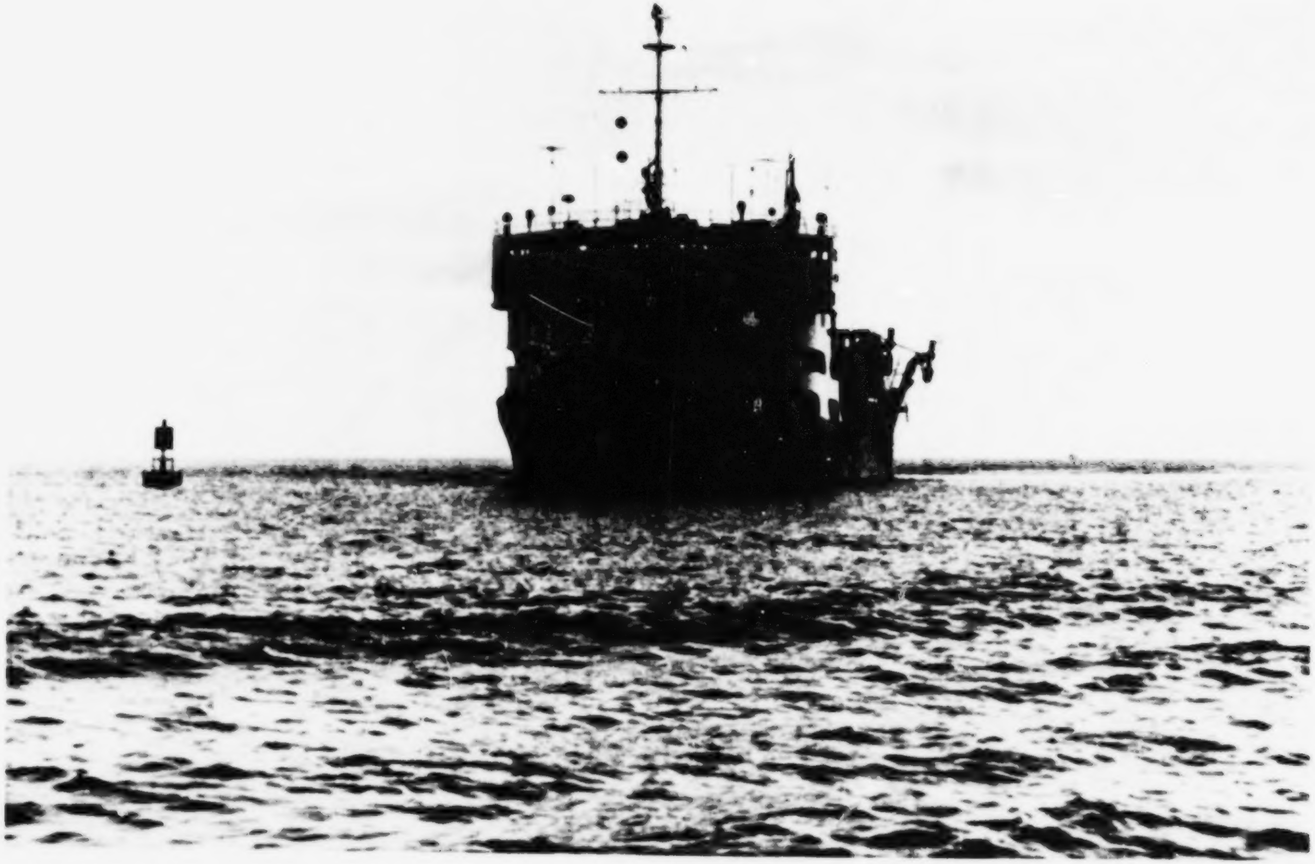


Figure 2. U.S. Army Corps of Engineers Dredge Gerig

In the system installation, as shown in Figures 3, 4, and 5, the waste water of culinary, laundry and sanitary origin was collected from the crew quarters in the aft portion of the vessel. The galley, which serves the entire crew, and the officer's lounge is located in the aft portion of the ship. Laundry waste was collected from two washing machines. The shower waste was collected from 10 showers, one bath tub and 43 sinks. Sanitary waste was collected from 13 toilets.

The crew operates three shifts a day, seven days a week with meal times scheduled 0715 to 0815, 1120 to 1220, and 1710 to 1810 hours. The vessel docks every second Thursday for repairs and supply.

An additional advantage was gained with the Gerig as it is one of three vessels studied and reported in an Environmental Protection Agency report entitled "Extended Aeration Sewage Treatment Plants on U.S. Corps of Engineers Dredges" by B. Sacks (Ref. 1).

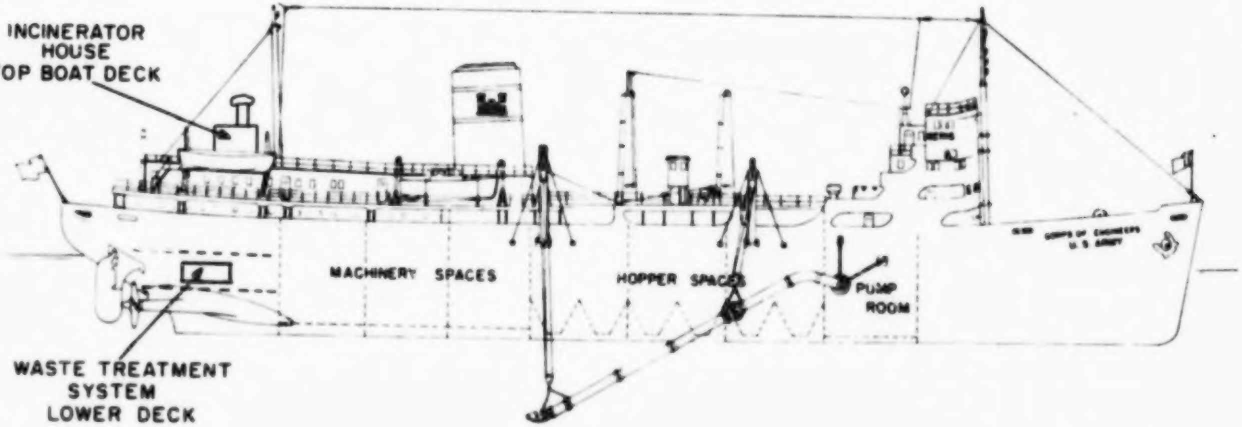
A survey of the wastes produced on board the Gerig was conducted in August 1969 and is reported, in detail, in Reference 2. A summary hydrographic profile, as shown in Figure 6, was established and used for final sizing of the waste treatment plant. Nominal daily flow was 2500 gal/day. Summary influent biochemical characteristics are shown in Table 3. These wastes comprised the total sanitary, laundry, and culinary wastes from the aft section of the Gerig.

C. Hardware Development

The laboratory development of the watercraft waste treatment system was reported in detail in the Phase I report entitled Component Development Report for Watercraft Waste Treatment System. This report is included, in its entirety, in Appendix A and covers the development, analytical and design activities conducted in the General Electric facilities in Philadelphia, Pa. from May 1969 until shipment of the system to the Gerig in August 1969.

To facilitate the discussion of waste treatment system performance, which follows in Section V, a discussion of how the hardware in the system was evolved is presented covering both laboratory development and later modifications during sea trials.

It was recognized at the inception of the program that full exploitation of the advantages of a watercraft waste treatment system utilizing electrocoagulation would require development of apparatus for comminution, solids separation, and further refinement of electrocoagulation technology. Absence of off-the-shelf components compatible with the practical goals of shipboard operation,


INCINERATOR
HOUSE
TOP BOAT DECK
WASTE TREATMENT
SYSTEM
LOWER DECK
MACHINERY SPACES
HOPPER SPACES
PUMP
ROOM
CORPS OF ENGINEERS
U.S. ARMY

GERIG — Commissioned 1947

CREW — 19 officers and 78 men

LENGTH — 351 feet 9 inches

BEAM — 60 feet

DRAFT — 24 feet 4 inches loaded

DISPLACEMENT — 8970 long tons loaded

Figure 3. Waste Water Treatment System Installation

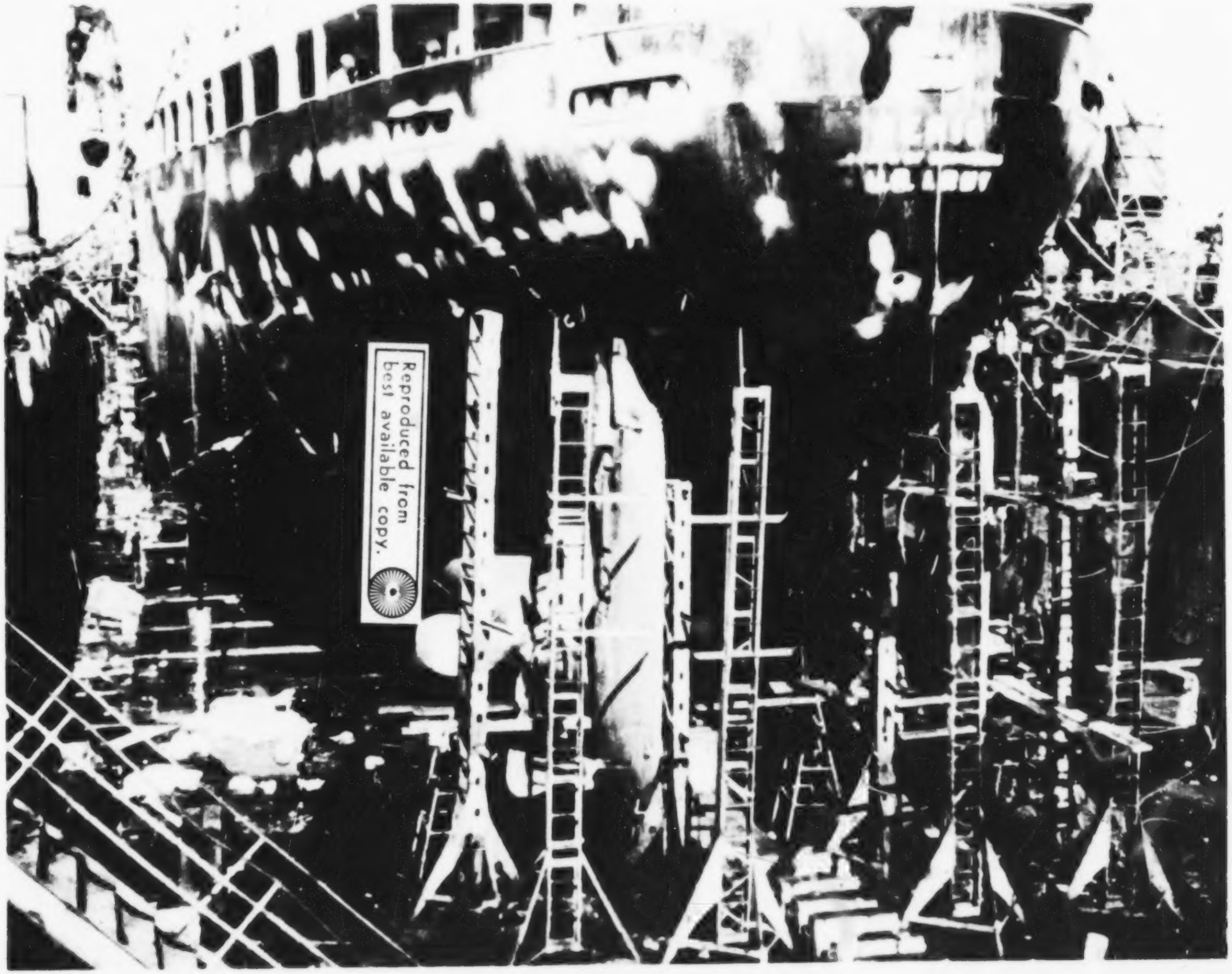


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Figure 4. Waste Water Treatment System, Shipyard Installation Tampa, Florida

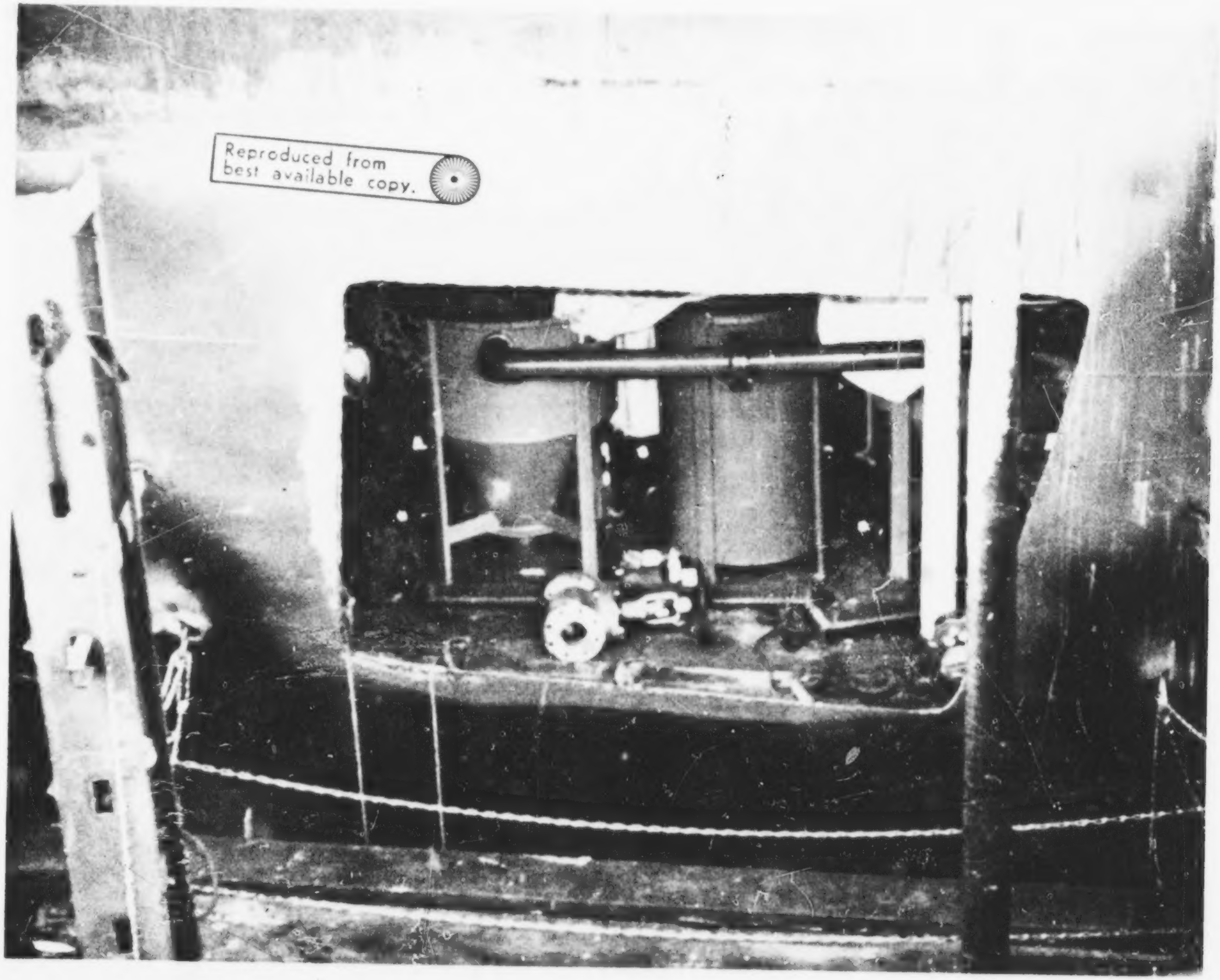

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Figure 5. Waste Water Treatment System, Shipyard Installation Tampa, Florida

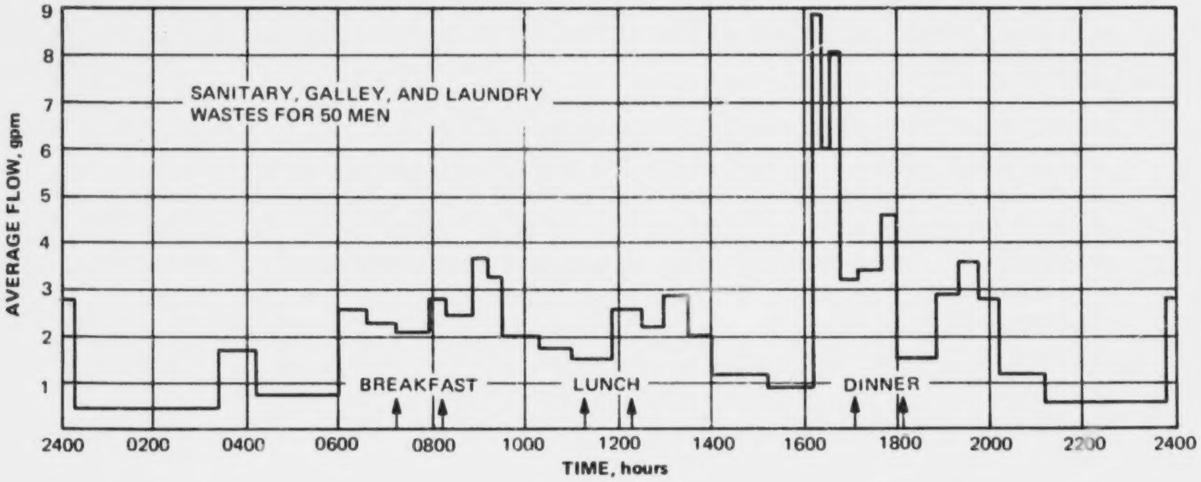

Figure 6. Wastewater Hydrograph for Dredge Gerig, August 1969

TABLE 3. SUMMARY INFLUENT WASTE CHARACTERISTICS, DREDGE GERIG, AUGUST 1969

Parameter	Average	Range
Flow	2500 gal/day	0-8.9 gal/min
Total Oxygen Demand, ppm	890	175-2300
Biochemical Oxygen Demand, ppm	650	175-880
Total Suspended Solids, ppm	600	125-1400
Total Volatile Suspended Solids, ppm	450	90-1200
pH	7.8	6.9-8.5
Conductivity μ mhos/cm	21000	9000-38000

suitable capacity, minimum cost, size and complexity dictated that development emphasize these three functional components.

Comminution

To permit pumping of combined sewage through minimum diameter piping, and optimize the electrocoagulation unit internal geometry for optimum scouring velocities and power requirements, a limitation upon maximum particle size was established.

To accomplish the design of a unit combining the sewage storage, comminuting, and pumping functions an adaptation was made of a comminution apparatus developed by General Electric for the Combined Sewers Separation Project under the auspices of the American Society of Civil Engineers, as reported in Reference 3. The household pump-storage-grinder development had as an objective solids comminution to a particle size not exceeding 0.25 diameter. The comminuted sewage facilitated transport by pumping through piping much reduced in diameter from conventional sanitary pipe. A detailed discussion of the alterations made, including establishment of pump rate and storage volume, may be found in Appendix A.

The unit referred to as pump-grinder consists of a double ended a-c motor which directly drives a specially adapted Hotpoint ® commercial grinder through a belt driven Moyno ® pump. The pump-grinder, shown in Figure 7, was installed in a 150 gallon tank to a depth within two inches of the tank bottom. This clearance, which is accessible from a special access port, allows volume for metallic objects to settle out harmlessly.

The pump-grinder has the versatility of being remotely located from the remainder of the system; in fact, more than one pump grinder, with a suitable holding tank, may be remotely located from the treatment plant serving as a collection point for sewage to be treated. This concept has been demonstrated on a Great Lakes ore carrier where the treatment plant is located in the engine room and the wastes from the deck crew, located in the bow 600 feet away, are collected and pressure transported under pressure through a one and one-half inch diameter pipe.

Electrocoagulation

The primary function of the electrocoagulation cell is to electrically generate the ferrous hydroxide coagulant in the presence of sewage solids. This is accomplished by arranging mild steel plates in a parallel matrix within a housing

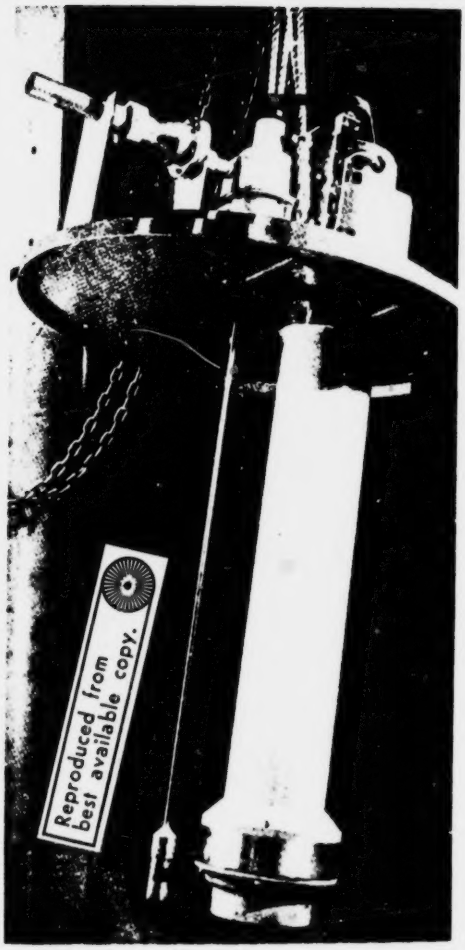

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Figure 7. Pump-Grinder

such that all waste water flow must traverse the spaces between plates. Alternate plates are energized with a d-c voltage which is controlled to maintain a prescribed current level. The reactions which occur include the release of ferrous ions from the anodes and the electrolysis of the waste water flowing in the plate spaces.

The detailed design activities and biochemical performance testing performed on various configurations of the electrocoagulation cell are reported in Appendix A. The configuration developed for incorporation in the demonstration system is described in Table 4.

It was determined in test that effective coagulation of the waste required a minimum of 50 mg/liter of ferrous ion. Figure 8 presents the measured iron in the effluent for various operating flows and currents, the current to flow ratio was established as 35 amp/gpm. For a pump-grinder rate of 5 gpm, the constant current required of the power supply was 175 amperes.

The electrocoagulation cell, depicted in Figure 9, is a wholly sealed unit. To vent hydrogen and remove foam generated in the sealed cell, the venting circuit shown in Figure 10 was developed. This venting arrangement was reviewed and approved by the Coast Guard and subsequently proved to be completely successful. The blower flowrate was established at 200 scfm at 1.1 in. H_2O pressure loss (the limitation on pressure loss in the vent stack to the upper boat deck). The evolution rate of hydrogen at 175 amperes is shown in Figure 11. The selected values yield a dilution ratio of air to hydrogen by volume of 5300:1, well below the four percent lower explosive limit.

Operation of the electrocoagulation cell in brackish water, as would be the case with the Dredge Gerig, requires the addition of hydroxyl ions to elevate the natural pH of the electrocoagulation cell effluent from the range 6 to 7 to greater than pH 9 for optimum flocculation. The flocculant aid selected from combined tests with the upflow clarifier was sodium aluminate.

Solids Separation

To assure clarity of the system discharge, a method to separate the solids coagulated in the electrocoagulation cell is required. Off the shelf contrifuges and cyclones evaluated did not meet the practical objectives of suitable capacity, moderate cost, automatic solids discharge, and reliability.

TABLE 4. ELECTROCOAGULATION CELL SPECIFICATIONS

Housing material	Epoxy - Fiberglas®
No. of plates	16
Plates thickness	0.25 in.
Plate Material	Steel, type 4130, cold rolled
Total area of plates	51.3 ft^2
Estimated plate life	600 hrs
Volume of cell	1.85 ft^3
Flow volume	1.3 ft^3
Wt. of iron	271 lbs
Hydraulic radius	0.47 in
Reynolds No.	8440
Flow rate	5 gpm
Current	175 amperes
Current density	6.8 amp/ft^2
Scrubbing air jets	19
Air Pressure	5 psig
Jet Nozzle diameter	0.125 in.

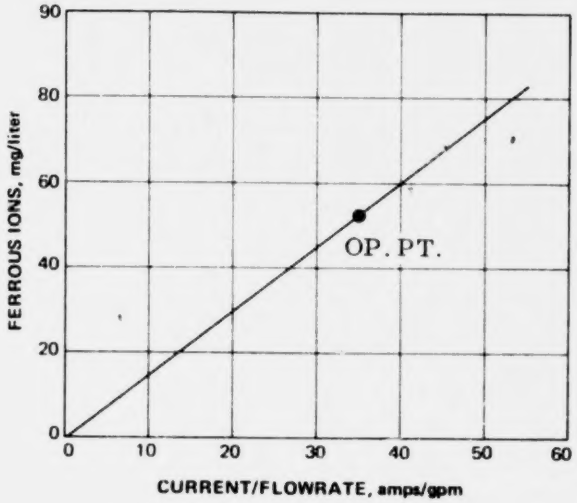

Figure 8. Fe^{++} vs. Current per Gallon per Minute

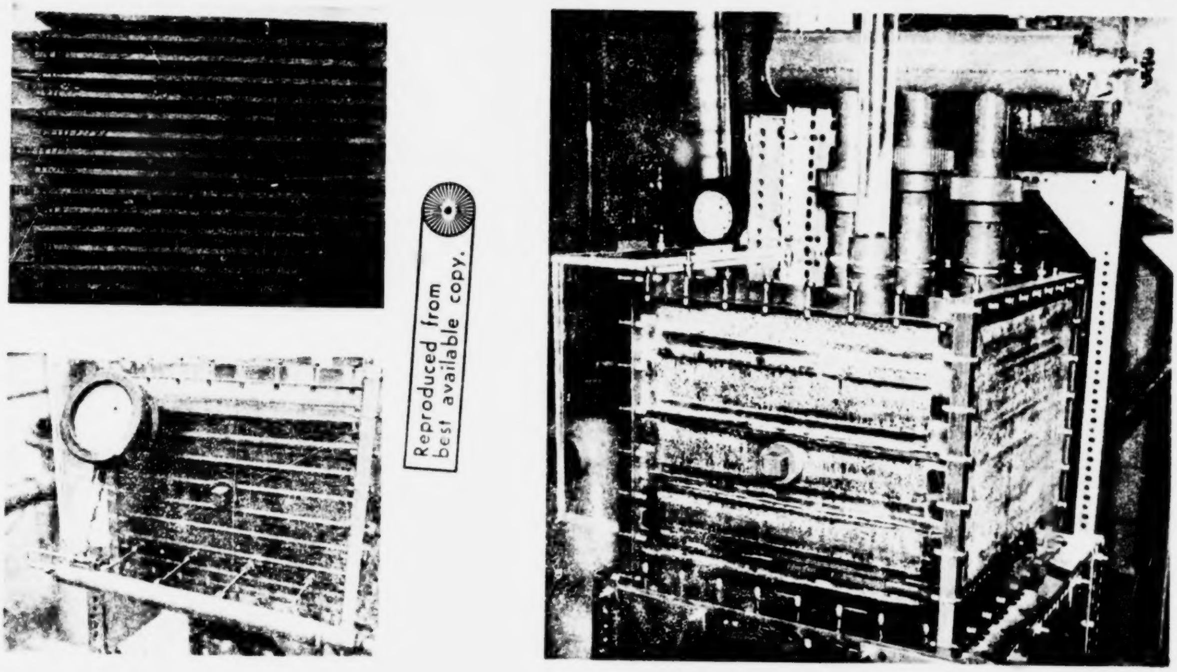

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Figure 9. Electrocoagulation Cell, Internal and External Views

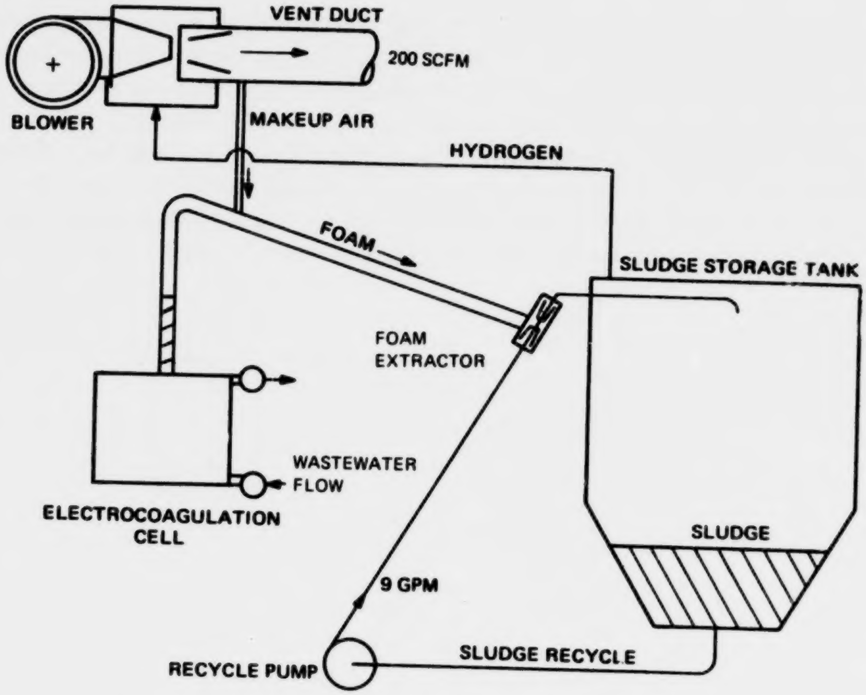

VENT DUCT
200 SCFM
BLOWER
MAKEUP AIR
HYDROGEN
FOAM
SLUDGE STORAGE TANK
FOAM EXTRACTOR
WASTEWATER FLOW
ELECTROCOAGULATION CELL
SLUDGE
9 GPM
RECYCLE PUMP
SLUDGE RECYCLE

Figure 10. Electrocoagulation Cell Vent Schematic

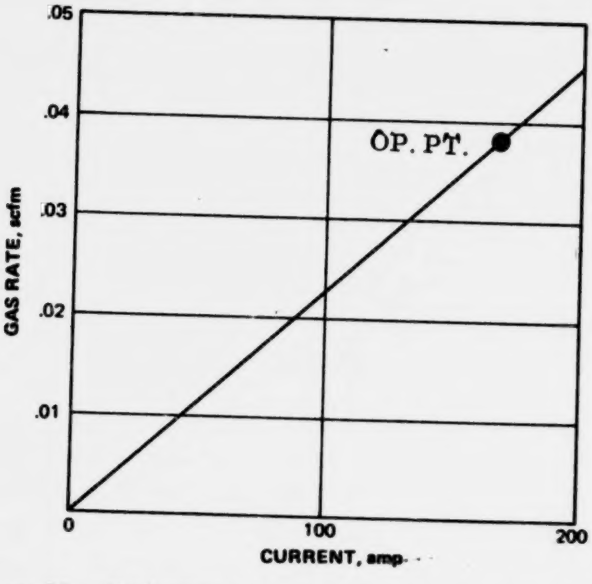
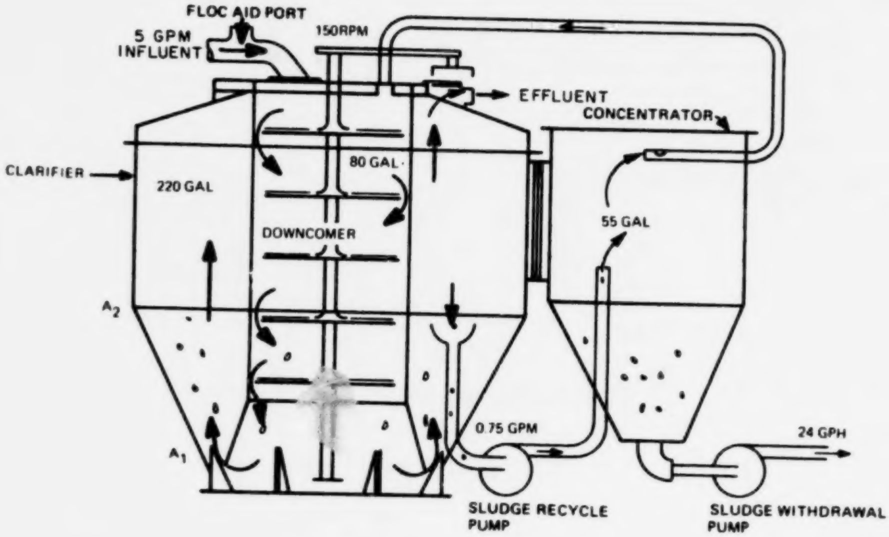


Figure 11. Hydrogen Gas Evolved vs. Applied Current

A concept which resulted in a means of solids separation in a short time period and in a compact volume is upflow clarification. The mode of operation of the upflow clarifier (see Figure 12) is to encourage the coagulation of solids by gentle agitation in a downcomer to facilitate formation of a sludge blanket, through which subsequent flow passes. The sludge blanket serves as a filter for suspended solids and possibly an adsorber of dissolved BOD. The discharge liquor is of high clarity (less than 50 ppm total suspended solids) when the clarifier flow rate and sludge settling rate are maintained in equilibrium.


FLOC AID PORT
5 GPM INFLUENT
150RPM
EFFLUENT
CONCENTRATOR
CLARIFIER
220 GAL
80 GAL
DOWNCOMER
55 GAL
A_2
A_1
0.75 GPM
24 GPH
SLUDGE RECYCLE PUMP
SLUDGE WITHDRAWAL PUMP

$A_2 = 11.47\ \text{ft}^2$

$A_1 = 0.59\ \text{ft}^2$

$V_1 = .113\ \text{ft/min.}$

$V_2 = .058\ \text{ft/min}$

Figure 12. Upflow Clarifier and Concentrator

It was established in development test that maintenance of the fluid-solids equilibrium under shipboard conditions of flow and influent solids loading required a stage wherein sludge was concentrated. Solids balance could, of course, be maintained by simply removing from the clarifier large quantities of the predominantly liquid sludge. There is a high economic premium upon the quality of sludge withdrawn, because ultimate disposal of this sludge is by incineration. Since one to two percent total suspended solids content for sludge is a common value for municipal treatment long term settling basins, this became the target concentration value for this apparatus. Rapid concentration of sludge was achieved by adding a second stage concentrator - adding 20 percent volume to the component for a ten fold compaction. Precedent for two stage clarification, in an application where sludge quantities were critical, is contained in Reference 4.

The physical configuration of the demonstration upflow clarifier is shown in Figure 12. The withdrawal of sludge from the blanket in the clarifier to the concentrator occurs continuously while the concentrator effluent is returned to the clarifier inlet. The concentrator sludge, which ranges from one to two percent total suspended solids (See Table 5), was scheduled for withdrawal by pump each 15 minutes of system operation. Conditions were established by average influent solids loading and daily hydraulic loading obtained from the Gerig Survey, Reference 2.

TABLE 5. WASTE TREATMENT CLARIFIER PERFORMANCE RESULTS

Run	11			12		13					14		15			16	
Clarifier flowrate (gpm)	5			5		5					5		5			5	
Flocculant aid rate (ppm)	50 sodium aluminate			50 sodium aluminate		100 sodium aluminate					100 sodium aluminate		100 sodium aluminate			100 sodium aluminate	
Test duration (min)	120			120		270					180		216			132	
Agitator speed (rpm)	54			54		120					150		150			150	
Sample time (min)	60	90	120	60	120	60	120	180	240	270	60	180	60	174	216	60	132
Clarifier influent TSS (ppm)	836	–	680	828	552	1000	824	716	400	484	872	672	856	436		752	356
Clarifier influent BOD (ppm)				396			408	390									
Clarifier effluent TSS (ppm)	26	–	20	50	34	34		22	40		68	58	108	58		52	28
Clarifier effluent BOD (ppm)					99			145	113								
Concentrator* sludge TSS (ppm)	12492	9348	11868						12470	11870	26358		20594			19987	
Clarifier influent Turb (JTU)						90		130	100	90	125	125	130	70		110	115
Clarifier effluent Turb (JTU)						24		16	18	24	28	28	30	17		30	24

*Obtained by pump withdrawal at 2 gpm.

It can be readily appreciated that ship's motion might affect such a clarifier if accommodation for sea states is not made. The development of Upflow Clarifier as reported in Appendix A focused upon establishment of a maximum overflow rate achievable (minimum component volume results) and upon minimizing of external influences upon performance. The demonstration upflow clarifier is shown in Figure 13 while mounted on the motion simulator test apparatus for the purpose of verifying performance at sea state conditions.

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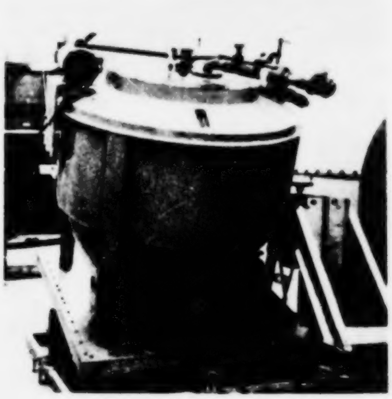
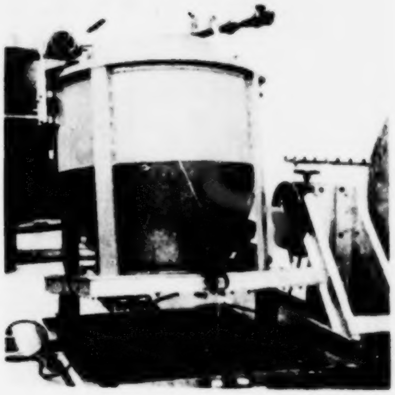


AT -20 DEG



AT +20 DEG

Figure 13. Upflow-Clarifier on Motion Simulator

Solids Disposal

Solids disposal was accomplished by incineration. Initial consideration was given to storage of the separated solids with subsequent dumping either at sea or at the dock. However, the tank size required to support the 14 day cycle of the Gerig between dockings, with the possibility of no sea dump, was excessive. A continuous means of solids disposal was therefore necessary and was accomplished by incineration.

A prototype, electric, home size incinerator, developed by the General Electric Advanced Environmental and Pollution Control Laboratory and field tested for over a year, had been used successfully to dewater and burn waste sludge. Additionally an incinerator developed for the U.S. Navy was provided by U.S. Naval Engineering Center at Annapolis. Evaluation of these units indicated that sludge incineration is a viable concept, but the units were incapable of operating at the rates of sludge expected from the system. Further, it was determined from the literature that a minimum combustion temperature of 1500°F was required to completely burn the organics present in the sludge in order to insure a completely odor-free exhaust. It was therefore necessary to develop an incinerator matched to the specific requirements of the waste treatment system. The incinerator supplied in this program was developed entirely with General Electric funds.

The incinerator requirements were determined by the needs of a somewhat larger waste treatment system being developed for U.S. Navy requirements.

The resulting incinerator has a capacity of 4000 pounds per day of liquefied sludge consisting of 90 to 100 percent liquid and 0 to 10 percent solids by weight. The liquid content can contain a high percentage of sea water with 1.5 percent average suspended solids content. Incineration products were a clear, odor-free, exhaust gas and a sterile ash containing essentially no residual organics.

The incinerator system to meet these requirements consists of a commercial burner unit fired with diesel oil, an air cooled, vortex type, combustion chamber with tangentially injected flame, and a motor driven fan and fuel pump with associated controls and safety interlocks. The sludge is atomized and entrained in the vortex until complete combustion is achieved thus eliminating the need for grates or screens which require frequent cleaning. The assembled system occupies a volume six feet long by five feet wide by four feet high, exclusive of stack and fuel tank, and weighs less than 1500 pounds.

The incinerator nominally operates at 500,000 Btu's per hour burner output with less than 0.5 pounds of fuel per minute and a sludge rate of 0.33 gallons per minute. Normal operating time of this incinerator on the Gerig was six to eight hours per day. The excess capacity of this incinerator could easily be used for disposal of bilge water and addition of a second, modified, nozzle would permit combustion of wet garbage or suitably prepared dry combustible wastes such as paper.

Ash removal was required every one to two weeks. Analysis of the ash revealed less than one percent organics (volatile solids) and the remainder primarily salt. An ash analysis is shown in Table 6. Figures 14 and 15 show the incinerator as installed on the Gerig. Figure 16 shows the incinerator installed as a integral part of a larger treatment plant.

Sea Trial Developments

During the initial test period, from Oct., 1970 to Dec., 1971, it was noted that the sludge blanket periodically overflowed the upflow clarifier weir during extended operation indicating a hydrodynamically unstable condition. A check of the system influent flows revealed rates of 3000 to 5000 gpd. A survey of the ship revealed that the flushometer rates on the toilets were set above specified limits. After adjustment of the flushometers, the daily flows were 2000-2500 gpd and the upflow clarifier appeared to stabilize.

During operation at Pascagoula/Gulfport, through January 14, 1971, it was observed that the sludge blanket once more passed over the weir resulting in high solids content in the effluent even though the system flow rate was within the design limit. These observations led to the conclusion that the system did not have sufficient solids storage capacity in the upflow clarifier and 50 gallon sludge concentrator. The 50 gallon solids concentrator was replaced with a 110 gallon concentrator. Solids carry-over was no longer observed during normal operation.

As a result of the increased concentrator size, the system became more sensitive to the development of anaerobic growth conditions due to the longer dwell time of sludge in the system. This was observed on several occasions while dredging at Port Canaveral, Florida in January 1971 and presisted until operations in Brunswick, Georgia in April 1971. In these locations, the background water was frequently reducing, as evidenced by positive oxygen reduction potential and low dissolved oxygen. Accumulations of hydrogen sulfide and methane gas were frequently disturbed during dredging operations. It was felt that a combination of the quality of the background sanitary water and an unusually low duty cycle accelerated the development of anaerobiosis. The problem was isolated after a rigorous water analysis period in Brunswick, Ga. with the Environmental Protection Agency water quality mobile laboratory and utilization of the on board water quality monitor.

TABLE 6. GERIG INCINERATOR ASH ANALYSIS

Ash Constituent*	Percent by Weight
Volatiles at 600°C	0.6%
Sodium	38.0
Chloride	28.0
Magnesium	6.0
Sulfate	9.0
Calcium	0.1
Iron	0.6
Silica	0.1
Phosphate	0.7
Fluoride	0.1
Zinc	0.01
Manganese, Copper	Trace
Cadmim, Silver, Nickel	No detection

*Sample from Feb. 21, 1971, Savannah, Ga.

In order to prevent anaerobic growth, a chlorinated recycle mode of operation was initiated at Boca Grande, Florida in April 1971. Fluid from the clarifier was continuously pumped into the concentrator while chlorine (12 ml/min.) was added to the concentrator effluent which was returned to the downcomer. This had the effect of maintaining an oxidizing environment in the clarifier/concentrator network and prevented the formation of anaerobic growth anywhere in the system.

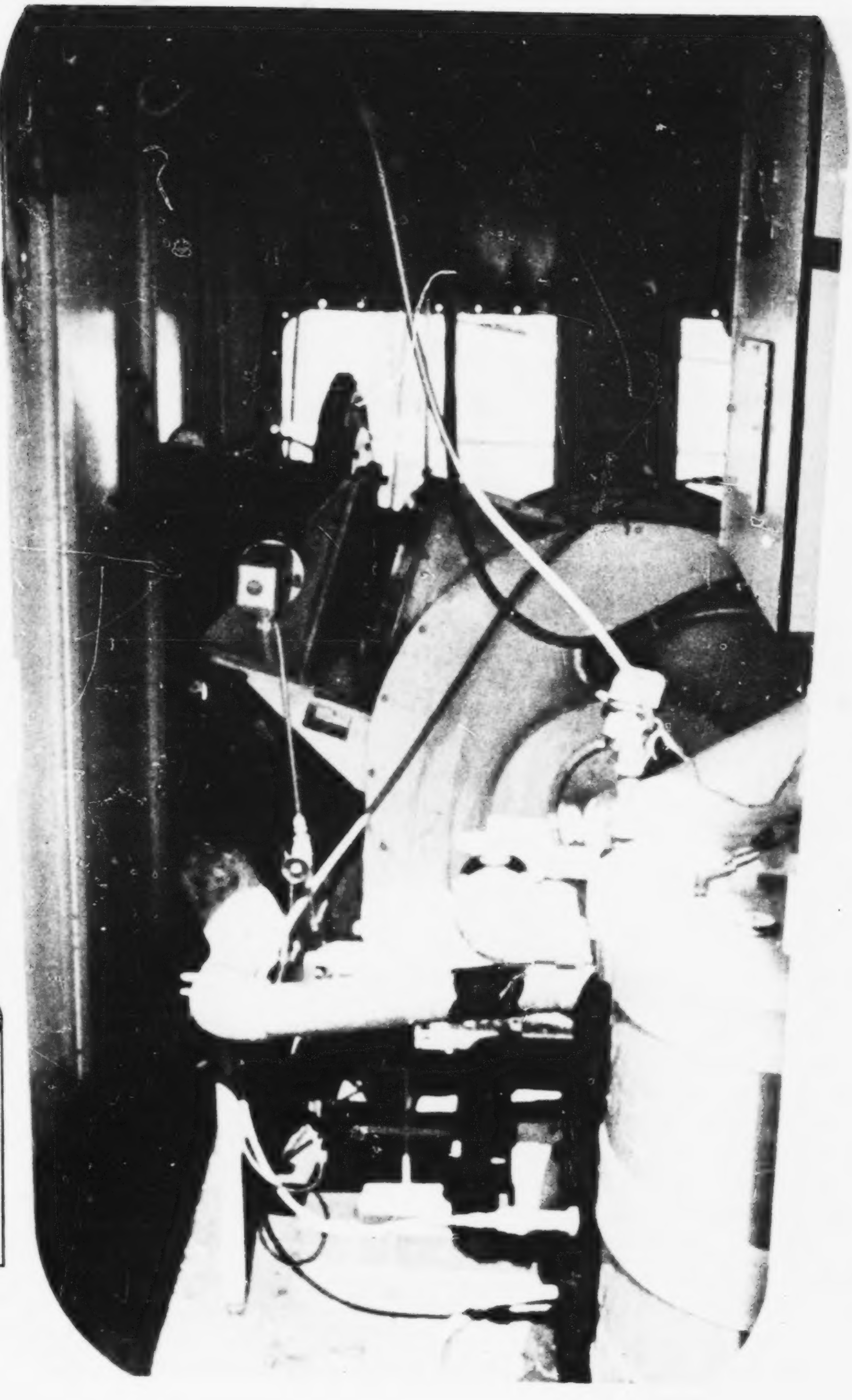


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Figure 14. Gerig Incinerator Installation

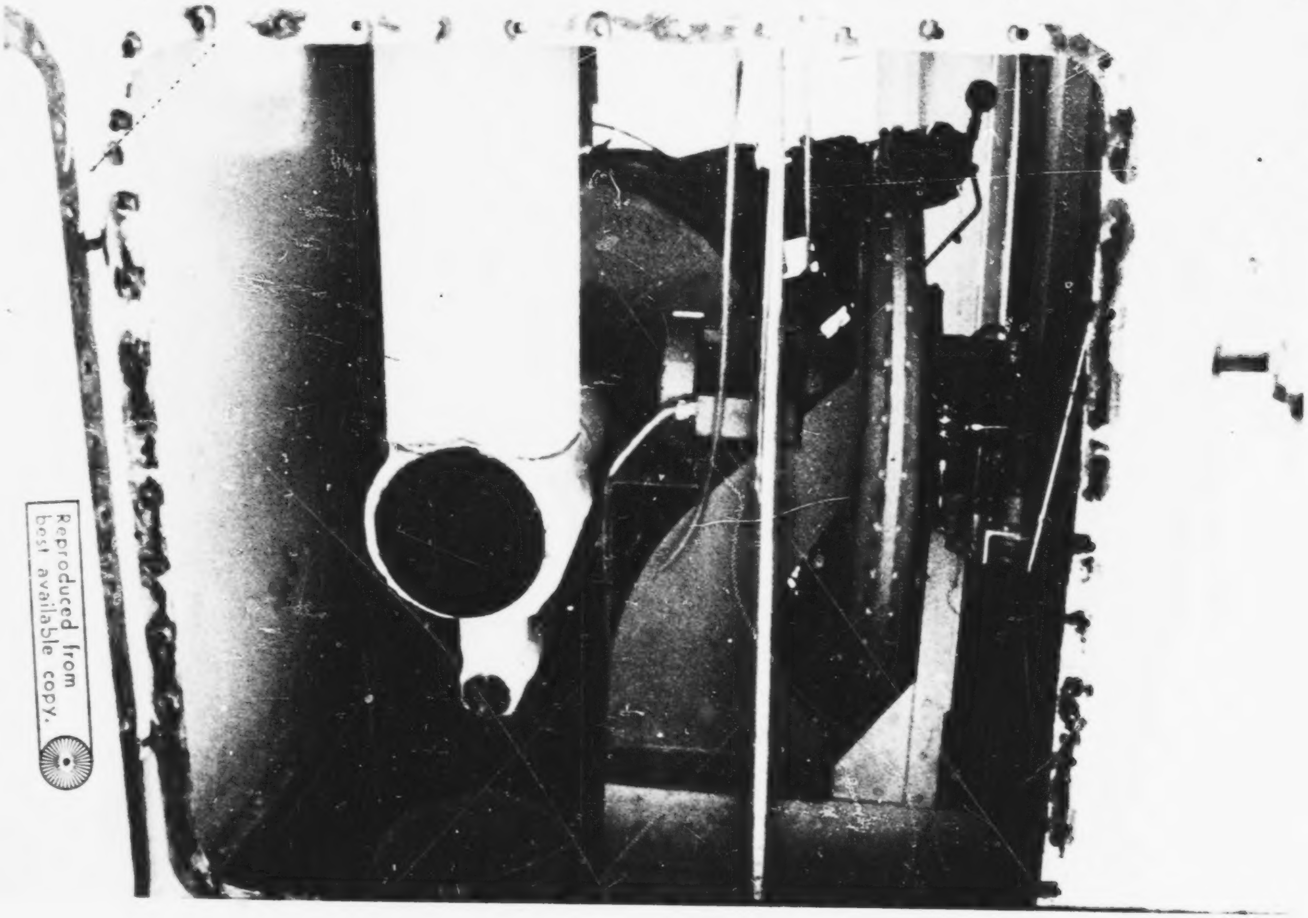

Figure 15. Gerig Incinerator Installation

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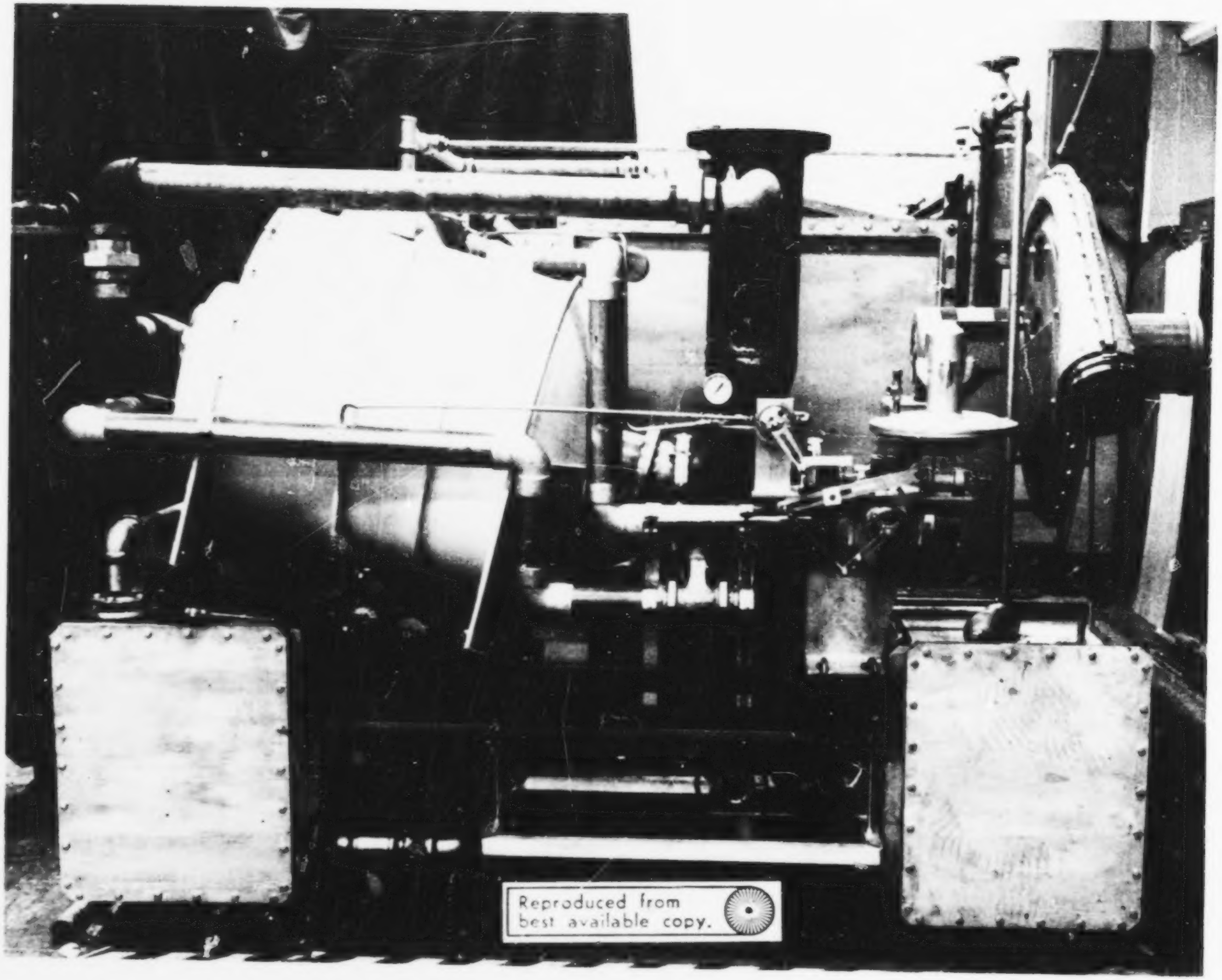

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Figure 16. Gerig Type Incinerator Installed on 7500 Gal/Day System

During subsequent testing, the system duty cycle decreased due to a decrease in total influent flow (1200-1600 gpd) due to crew shore leave. This allowed a reversal to the 50 gallon concentrator without a decrease in sludge concentration or reoccurrence of sludge carry over into the system effluent.

During solution to the septicity problem, the high fraction of dissolved BOD in the influent was identified. This resulted in higher than desired BOD in the effluent. Several candidate methods for oxidation and adsorption of BOD were evaluated in a shore based laboratory utilizing actual ships wastes during the period April through August 1971. Of the methods evaluated, only granular activated carbon had any appreciable effect in reducing the Gerig's soluble BOD. Based on the laboratory results, full scale carbon absorption equipment was installed aboard the Gerig in July 1971 to demonstrate and evaluate the effectiveness of granular activated carbon for BOD reduction.

Four carbon columns were installed on the Gerig downstream of the solids separator. Each was 12 inches in diameter by 60 inches high and filled a 3-1/2 foot column (70 pounds) of granular activated carbon (DARCO® 8 x 35 mesh, Atlas Chemical Co.). These columns were operated in series and the flow was maintained at 4.6 gpm. Flow was in an upward direction in each column. Downstream of the carbon columns was an aeration tank followed by effluent chlorination. The effluent from the aeration tank was automatically diverted either to the chlorinator or recycled back to the first carbon column.

The prototype carbon absorption system selected for installation on the Gerig was designed to meet the particular requirements imposed by shipboard use. The upflow mode of operation offers an advantage over typical land based packed-bed columns in that up-flow operation eliminates the fouling and solids build-up associated with packed-bed operation. This precludes the necessity for frequent back flushing of the bed to remove the particulate build-up. Secondly, literature references indicate that essentially the same treatment is obtained for either mode of operation.

The size of the carbon columns and grade of carbon was selected to obtain a minimum two month carbon life while treating the entire Gerig effluent. DARCO® 8 x 35 mesh carbon is a waste water carbon. The fine mesh size gives the benefit of a greater capacity and a higher rate of absorption of organics from the waste water than a carbon composed entirely of coarse mesh particles.

Testing was terminated in Moorehead City, N.C. in August 1971. At the time of test completion, the life of the carbon columns was far from expended, as evidenced by the fact that BOD reduction was occurring exclusively in the first two columns of the four column series. The first two columns were not expended and the remaining two were essentially unused.

The carbon column configuration, which occupies very little floor space, lends itself to replenishment by removal of one column at a time. By suitable PVC hand valves, the sequence of the columns can be easily changed and replacement of a column can be accomplished while the waste treatment system is operating.

SECTION V

RESULTS AND ANALYSIS

A. Summary-Biochemical Performance

During the course of the study the treatment system was required to treat waste in a wide variety of background waters. Initial shipboard testing in October 1970 was performed with fresh water as the ships supply. The ship then operated along the Gulf coast, around the Florida coast and northward to North Carolina. During the sea trials, sea water was used as the flushing water in heads. When the ship was dredging and dumping, the water supply to the sanitary system often contained large amounts of grit, sand or mud.

System operating temperatures were largely determined by the ambient water and air temperatures of the ships location. Process temperatures varied from 75°F (Brunswick, Ga.) to 100°F (Boca Grande, Fla.).

The influent flow rates to the systems varied widely during the study; from an estimated 5900 gpd at the beginning of the study to 1500 gpd at the end. At one point the flow was as low as 700 gpd. Typical system duty cycles are shown in Figure 17.

Inspection of the analytical data summary, Table 7, shows that the BOD and suspended solids content of the influent increased significantly during the course of the study. This is thought to be due to more and more rigid enforcement of overboard dumping regulations. The captain and officers of the Gerig strictly enforced these regulations.

Sea trials started in December, 1969. Process performance of the systems was monitored by on-board instrumentation per Table 8. Shore based laboratory analysis of BOD, Coliform, and suspended solids began after adjustment of floc aid and chlorine addition rates. Daily averages of biochemical performance, during sea trials, are shown in Table 7. A complete compilation of the water analysis data is contained in Appendix B.

A biochemical evaluation of the system was conducted prior to leaving the shipyard in October. During this period the sanitary water used by the ship was Tampa City water. Laboratory analysis indicated that the system was capable of treating the Gerig's waste to the approximate target levels of 50 ppm BOD and

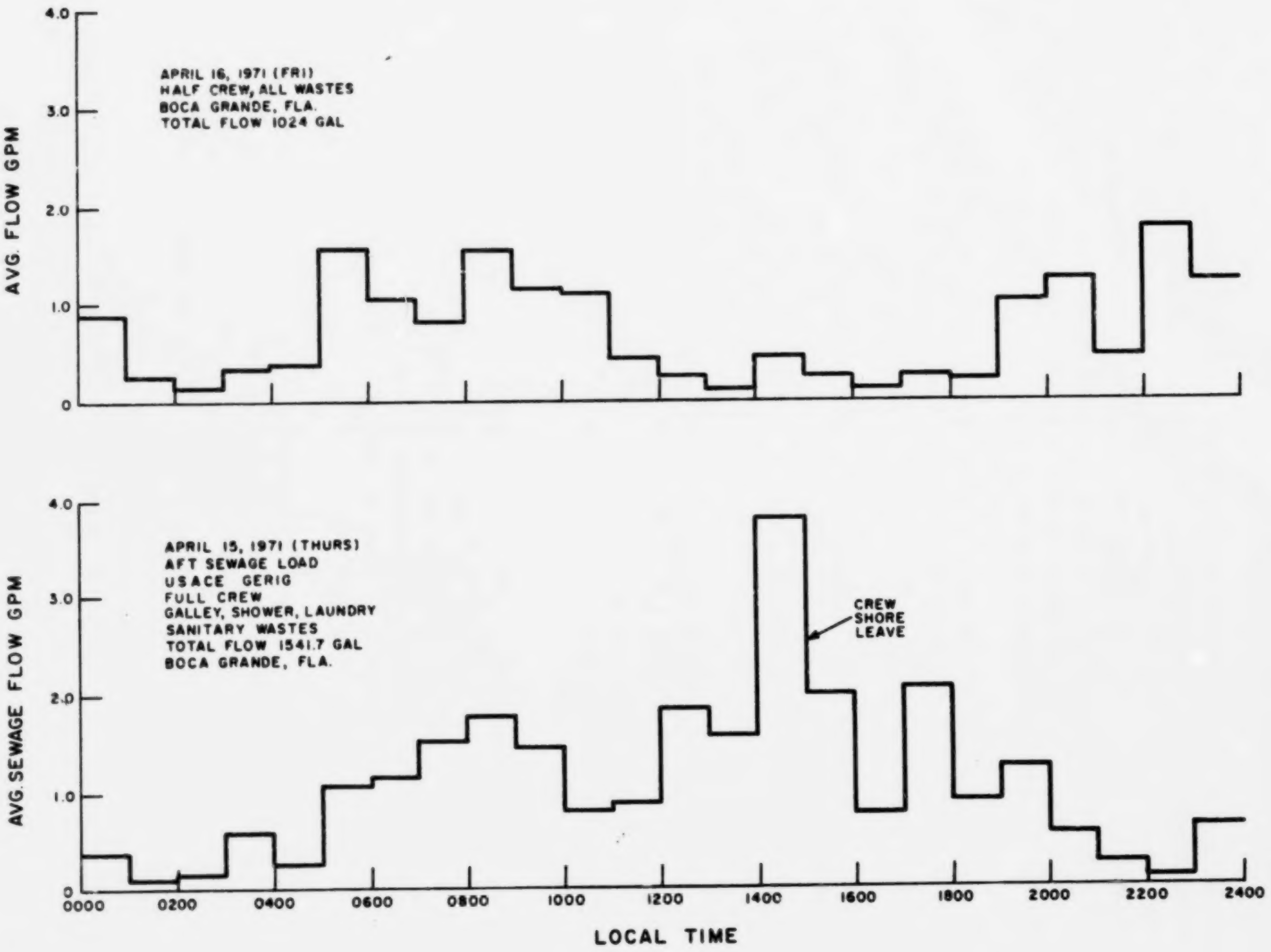


Figure 17. Typical Gerig Hydrograph During Sea Trials

TABLE 7. DAILY SHIPBOARD WASTE TREATMENT SYSTEM WATER ANALYSIS AVERAGES

Location/Dates	BOD_5* Inf.	BOD_5* Eff.	S.S. ppm Inf.	S.S. ppm Eff.	pH Inf.	pH Eff.	Res. Cl_2 ppm	Colif. Col./100ml	Comments
Tampa Shipyard									
10-27-70	—	78	—	45	—	—	—	—	
10-28-70	270	79	488	25	8.4	9.6	—	—	Operating on Tampa City Water at Shipyard
10-29-70	170	65	566	57	8.2	9.1	—	—	
Averages	220	74	527	42					
Pascagoula, Miss.									
1-8-71	140	15	420	20	—	—	—	—	
1-9-71	190	20	150	20	—	—	—	—	
1-10-71	270	75	430	5	—	—	—	—	
1-11-71	150	40	1340	10	—	—	—	—	
1-12-71	200	15	—	10	—	—	—	—	Excessive water flow due to high flushometer settings
1-13-71	45	40	65	15	—	—	—	—	
Averages	166	33	481	13					
Brunswick, Ga.									
3-11-71	575	220	692	54	—	—	—	—	
3-13-71	1000	315	907	47	—	—	—	—	No ship power - system septic as evidenced by effluent odor, color, positive ORP and low DO.
3-14-71	375	183	497	70	7.0	8.4	1	>1 x 10^3	
3-15-71	1070	216	617	19	7.4	8.6	—	>1 x 10^3	
3-16-71	630	—	688	58	7.0	—	—	—	Low flow - system septic
3-17-71	320	219	390	83	7.5	7.5	22	—	
3-19-71	430	393	360	66	7.1	7.9	29	>1 x 10^3	System septic

*Represents an average of 4 influent and 4 effluent samples.

TABLE 7. DAILY SHIPBOARD WASTE TREATMENT SYSTEM WATER ANALYSIS AVERAGES (Continued)

Location/Dates	BOD_5		S.S. ppm		pH		Res. Cl_2 ppm	Colif.. Col./100ml	Comments
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.			
3-20-71	805	272	550	60	7.4	8.1	62	>1 x 10^3	
3-21-71	730	172	590	47	7.5	8.8	17	<1.0	
3-22-71	700	282	570	48	8.2	8.8	23	<1.0	
3-23-71	667	241	490	87	7.8	8.1	97	<1.0	
3-24-71	645	202	710	108	6.9	8.7	68	<1.0	
3-25-71	272	202	320	78	7.4	8.7	34	2 x 10^3	
3-26-71	498	206	560	60	7.5	8.6	47	<1.0	
3-27-71	506	306	460	48	7.2	8.4	20	>1 x 10^3	
3-28-71	607	224	415	107	7.3	8.6	39	<1.0	
3-29-71	385	175	150	18	7.6	8.9	80	<1.0	
3-30-71	1120	87	630	18	7.3	8.5	118	<1.0	
3-31-71	320	155	290	43	8.0	8.6	27	9	
4-1-71	915	330	600	46	7.7	8.0	22	<1.0	Air bubbler added to effluent chlorination tank
4-2-71	1000	164	860	25	7.6	8.6	17	<1.0	
4-3-71	585	261	390	36	7.6	8.7	57	<1.0	
4-4-71	547	250	310	77	7.2	7.6	23	<1.0	
4-5-71	715	219	520	69	7.0	7.6	35	<1.0	
4-6-71	502	246	430	71	6.4	8.1	88	3	
4-7-71	657	213	560	60	7.6	8.1	44	235	
4-8-71	510	191	—	—	7.5	8.8	27	—	
4-9-71	390	183	—	—	7.6	8.5	82	—	
Averages	625	218	525	56					

TABLE 7. DAILY SHIPBOARD WASTE TREATMENT SYSTEM WATER ANALYSIS AVERAGES (Continued)

Location/Dates	BOD_5 Tot. Inf.	BOD_5 Sol. Inf.	BOD_5 Eff.	S.S. ppm Inf.	S.S. ppm Eff.	pH Inf.	pH Eff.	Res. Cl_2 ppm	Colif. Col./100ml	Comments
Boca Grande, Fla.										
4-16-71	975	60	61	1880	550	—	—	—	— —	
4-17-71	500	135	225	2060	500	—	—	—	— —	High effluent solids due to blanket carry-over-at initiation of recycle
4-19-71	690	345	42	1110	115	—	—	—	— —	
4-20-71	305	130	68	920	70	—	—	—	— —	
4-21-71	440	100	42	540	140	—	—	—	— —	
4-22-71	830	480	32	2420	180	—	—	—	— —	
Averages	534	178	78	1490	257	—	—	—	— —	
Southport, N.C.										
4-29-71	772	225	128	715	55	8.7	9.0	26	<1.0	
4-30-71	590	236	210	320	33	7.5	8.9	13	<1.0	
5-1-71	450	220	215	250	150	7.8	9.0	47	—	
5-6-71	780	250	320	—	85	8.0	8.0	17	—	
5-10-71	740	380	240	650	60	7.3	8.9	8	—	EC cell power supply failure
5-11-71	370	—	450	810	75	6.9	9.2	18	—	
5-12-71	1100	590	292	750	79	7.4	9.1	16	—	Intermittent EC cell operation; power supply troubleshooting
5-16-71	445	—	166	360	47	7.9	8.8	24	—	
5-17-71	746	415	267	390	59	6.9	9.3	19	—	
5-18-71	480	—	195	380	35	8.2	9.5	18	—	

TABLE 7. DAILY SHIPBOARD WASTE TREATMENT SYSTEM WATER ANALYSIS AVERAGES (Continued)

Location/Dates	BOD_5 Tot. Inf.	BOD_5 Sol. Inf.	BOD_5 Eff.	S.S. ppm Inf.	S.S. ppm Eff.	pH Inf.	pH Eff.	Res. Cl_2 ppm	Colif. Col./100ml	Comments
5-24-71	330	140	207	520	90	8.7	9.1	40	—	
5-25-71	787	—	367	—	—	8.3	9.2	25	—	
5-26-71	730	—	340	—	—	7.8	9.1	55	—	
6-20-71	300	—	147	—	—	7.4	9.0	-*	—	$KMnO_4$ added to clarifier
6-21-71	200	—	575	—	—	6.7	8.9	-*	—	
6-22-71	290	—	180	—		9.2	8.9	-*	—	
6-23-71	—	—	—	—	—	—	—	—	—	Discontinued use of $KMnO_4$
6-24-71	880	—	170	—	—	8.6	9.5	33	—	
6-25-71	180	—	170	—	—	6.1	8.8	11	—	
6-26-71	400	—	155	—	—	7.1	8.9	17	—	
7-7-71	590	—	205	670	27	—	—	—	—	
7-8-71	390	—	170	780	39	—	—	—	—	
7-9-71	731	440	234	—	—	7.2	7.2	69	—	
7-10-71	430	340	293	—	—	8.7	9.2	45	—	
Averages	533	316	248	550	64					
7-14-71	440	—	47	1510	20	8.6	7.6	5	—	Carbon column in operation
7-15-71	600	—	61	1570	11	7.9	8.0	0	—	

*$KMnO_4$ used in conjunction with chlorine.

TABLE 7. DAILY SHIPBOARD WASTE TREATMENT SYSTEM WATER ANALYSIS AVERAGES (Continued)

Location/Dates	BOD_5			S.S. ppm		pH		Res. Cl_2 ppm	Colif. Col./100ml	Comments
	Tot. Inf.	Sol. Inf.	Eff.	Inf.	Eff.	Inf.	Eff.			
7-16-71	380	—	125	1180	14	7.8	7.8	0	—	
7-17-71	220	—	90	500	5	8.2	7.5	0	—	160 gal. Concentrator Removed
7-19-71	400	120	50	580	22	8.7	7.7	0	—	50 gal. Concentrator Installed
7-20-71	600	160	69	1770	38	8.8	8.1	0	—	
7-21-71	240	140	60	420	30	8.5	7.7	0	—	
7-23-71	580	330	109	580	101	7.9	8.0	0	—	
7-26-71	340	170	60	460	65	4.4	7.4	0	—	
7-27-71	720	440	44	640	36	8.8	7.4	0	—	
7-29-71	340	115	66	390	75	7.8	9.0	75	—	
7-30-71	330	80	108	230	53	7.9	8.7	—	—	
8-1-71	—	—	132	290	55	9.0	8.6	—	—	
8-2-71	840	280	150	460	155	7.7	8.6	—	—	Columns septic as evidenced by odor, color, positive ORP and low DO
8-5-71	1200	540	200	—	—	8.2	8.3	29	—	
8-7-71	1200	510	198	—	—	7.8	8.5	26	—	
8-8-71	360	160	60	—	—	8.6	8.7	12	—	Aeration Added
8-9-71	990	430	64	—	—	8.0	8.7	9.0	—	
Averages	575	267	94	756	49	—	—	—		

TABLE 8. ON-BOARD INSTRUMENTATION

Analytical Instrumentation For On-Board Monitoring Of System Performance	
Performance	Instrument/Method
1. Residual Chlorine	Automatic Titrator Phenylarsene Oxide
2. Iron	Hach Field Test Kit
3. Dissolved Oxygen	Beckman Probe
4. Conductivity	Honeywell Probe
5. pH	Beckman pH Probe
6. Oxidation-Reduction Potential	Beckman Probe
7. Turbidity	Hach-Falling Stream
8. Turbidity	Hach-Back Scatter
9. Sludge Settleability	Bird - Gang Stirrer

Note: Items 3 through 7 were incorporated into an automated water quality monitor.

100 ppm suspended solids. BOD and suspended solids reductions of 66 and 92 percent respectively were obtained. Average values for this period were:

	BOD_5	S.S.
Influent	220 ppm	527 ppm
Effluent	74 ppm	42 ppm

Influent resembled standard municipal waste chemically and physically.

At Pascagoula/Gulfport in January 1971 the Gerig was dredging approximately 10 miles offshore in sea water. The conductivity of the influent to the waste treatment system varied from 30,000 to 50,000μ mhos/cm. Reduction of 80 percent in BOD and 97 percent in suspended solids was achieved. Average values for this period were:

	BOD_5	S.S.
Influent	166 ppm	481 ppm
Effluent	33 ppm	13 ppm

The influent again had the general appearance (chemical and physical) of domestic waste. It was noted however, that due to the excessive flows, which were up to 200 percent of the design flow rate, the solids blanket would periodically carry over the clarifier weir. The actions taken to correct this were to recalibrate the toilet flushometers to their specified operating range and installation of a larger solids concentrator in order to give more capacity for the retention of separated solids.

As a result of satisfactory biochemical performance, an intensive 30-day system performance evaluation at the next dredging area, Brunswick/Savannah, Ga., was begun. Here the Gerig worked in sea and estuarine water. During March and April, 1971, laboratory analyses were performed by personnel from the General Electric Environmental Sciences Laboratory and the Cincinnati Water Quality Office of the Environmental Protection Agency. The work was performed in a mobile laboratory facility supplied by Environmental Protection Agency, Cincinnati.

A significant increase in both influent and effluent BOD was observed. Also it was found that the low duty cycle of the system, at the adjusted influent flow, caused the development of anaerobiosis in the system. Corrective measures were incorporated into the system operations in order to reverse the anaerobic tendency. This involved the introduction of chlorine into the clarifier and sludge concentrator during the daily 14 hour low flow periods. In addition the chlorine feed to the effluent was adjusted to give a minimum residual of 20 ppm. During this test period average values were:

	BOD_5	S.S.
Influent	625 ppm	525 ppm
Effluent	218 ppm	56 ppm

Reductions of 64 and 89 percent were achieved for BOD_5 and suspended solids respectively. The data showed extreme variability, influent BOD's ranged from a low of 100 ppm to a high of 1980 ppm. Influent suspended solids loadings were also quite variable, daily averages ranging from 300 to 1000 ppm, with individual values as low as 40 and as high as 1600 ppm.

The Gerig proceeded to Boca Grande, Florida in mid April 1971 where steps were taken to prevent the development of septicity which was thought to be a contributing factor to the high effluent BOD. A continuous, clarifier to sludge concentrator, chlorinated recycle system was installed. This maintained an oxidizing environment in the system which prevented the establishment of conditions for anaerobic growth. After it was established that no anaerobic growth was occurring by intensive measurement of parameters such as ORP, DO levels, chlorine demand, pH and odor, BOD testing was resumed.

Analysis at an independent laboratory gave the following results after six days of testing:

	Total BOD_5	Soluble BOD_5	Total Susp. Sol.
Influent	534	178	1490
Effluent	78	-	*257

*Due to solids carry-over during system adjustment.

Percent reduction was 85 and 83 for BOD_5 and suspended solids respectively. The data also indicates that the soluble fraction of the BOD was approximately 30 percent of the total.

In light of these results it was decided to resume demonstration testing in the area of Southport/Wilmington, North Carolina. The Environmental Protection Agency mobile laboratory facility was again employed, manned by General Electric personnel who had been trained previously in the EPA analytical methods. High effluent BOD's were again obtained.

Average values were:

	BOD_5	TSS
Influent	553	550
Effluent	248	64

Regular determinations of the soluble fraction of the influent BOD were incorporated into the test program. The soluble portion averaged approximately 60 percent of the total. An intensive laboratory test program was initiated in order to determine the source of the soluble material. A survey of the ship identified several sources of soluble BOD. An investigation to determine a means of chemically oxidizing this material within the existing system configuration was unsuccessful. Carbon adsorption was added to the system in July 1971. The carbon columns were installed to accept the system effluent; initial performance was excellent. A tendency toward septicity was found after several days of operation. This was due to inadequate aeration of the columns, again, a strong function of low system duty cycle (3-4 hours out of 24). A continuously aerated recycle loop was installed for periods when the system was inoperative. This was able to keep the columns aerobic and they recovered their activity.

Averages for this period were:

	BOD_5	S.S.
Influent	575	756
*Effluent	94 (78)	49

*If values where the columns were septic are neglected, the mean effluent BOD_5 was 78 ppm

While the carbon columns were installed, the percent reduction for BOD and S.S. were 84 and 93 respectively.

The carbon columns performed quite well with the exception of the development of septicity due to inadequate aeration (see Table 7, 7/14/71 to 8/9/71). At the time of installation the system influent flows were on the order of 900-1600 gpd, resulting in 3 to 5 hours of operating time per day. No air was admitted during the non-operating time and additional column compaction occurred. To provide a constant air supply and prevent increases in packing density, a recycle loop was installed (see Figure 1). In this mode of operation a constant supply of air saturated water was presented to the column when the treatment system was not processing. This kept the columns aerobic and also helped to maintain uniform packing density to prevent channeling.

The columns were not installed for a long enough period to determine their total capacity for the dissolved BOD material. The efficiency of the columns decreased when there was septicity, however, this was reversed when the columns were made aerobic.

Coliform determinations were routinely performed at Tampa, Fla. and Brunswick, Ga. (Table 7). Spot checks were also made at Southport, N.C. Coliform bacteria levels were easily controlled in the effluent throughout the test to less than the target value of 240 MPN col/100 ml. It was also found that sudden or persistent rises in effluent coliform count could be used as an indicator for problems elsewhere in the system such as septicity or solids carryover. The chlorinated recycle mode of operation maintained a sufficient level of chlorine throughout the system to prevent the growth of coliform organisms.

Conclusions

The ship's combined influent waste showed extreme variability over very short operating cycles. Variation occurred in almost every parameter measured. The most striking however, were the range of suspended solids and BOD concentrations.

The persistent presence of such a large soluble and refractive BOD fraction puts the Gerig influent into the industrial rather than domestic, waste category. The data imply that the large soluble fraction was contributed by common ship's cleaning chemicals that are used for routine maintenance and can be expected to be constantly found in the influent.

The growing enforcement of overboard dumping restrictions will serve to increase the strength of waste to be treated. This will be true for "sanitary only" situations as well as for treatment of total waste since much of the soluble BOD causing material can be easily disposed of into urinals, toilets and head drains.

Chemical results from independent laboratories were often found to be erratic and sometimes varied widely between different labs. This was judged to be due to their lack of experience in measuring high strength waste and consequent lack of adjustment for increased waste concentrations. It is our conclusion that the analysis should be performed by a laboratory that has some experience with water type to be analyzed. Critical information that is required by the analyst and must be adjusted for in the test procedure is:

1. Extreme range in sample strength (factor of 20 possible).
2. High immediate oxygen demand (IOD).
3. Very high chemical oxygen demand (COD).
4. Presence of toxic chemicals.
5. Higher than normal chlorine content.
6. Interference of waste chemicals with test reagents.

B. Discussion - Biochemical Performance

The results of an earlier intensive, in-house test program (See Appendix A) indicated that the General Electric system would be able to treat shipboard waste to the desired target levels. This implied BOD loadings on the order of 400-500 ppm with approximately 75 percent of the BOD constituents being suspended material. It was anticipated that excesses in soluble BOD could be reduced by oxidation with chlorine. Suspended solids and coliform removal had been demonstrated to be excellent under all operating conditions. The actual wastes from the Gerig, however, proved to be quite different from those encountered using sanitary office building waste and simulations of shipboard waste. The average soluble portion of the BOD aboard the ship was on the order of 50 percent. When the influent total BOD was highest (1000 to 2000 ppm) its major component was soluble (60 to 80 percent). The result of this high soluble BOD fraction prevented meeting the target levels with the system as originally configured.

As a result of the BOD problem, a field laboratory analysis program was initiated. Its objectives were to attempt to identify the causative factor for the high soluble BOD loadings and to develop an environmentally compatible chemical treatment process for oxidation of this material.

As the first step in the investigation, a comparison was made of analytical techniques between the Standard Environmental Protection Agency method (references 5 & 6) and those used by two independent testing laboratories. Wide variation in results between the three laboratories was found in the analysis of simultaneously analyzed samples of system influent and effluent. Further investigation indicated that the independent laboratories varied from the Standard Method (reference 5) in ways that could lead to obtaining low results. On the basis of these results, it was decided that all systems performance evaluation would be conducted by EPA trained GE personnel using the EPA modification of the standard method. A further modification was made when further study showed that the Winkler titration agreed with the results obtained using a Weston and Stack dissolved oxygen meter. This modification allowed a significant increase in the number of samples that could be processed.

As the second step in the program, a survey of the Gerig was made to determine what soluble materials were used during routine ships operation that could find their way to the waste treatment system. Nine cleaning compounds were identified. 100 ppm concentrations of these components were tested for BOD activity. A standard solution of glucose/glutamic acid was made up as a BOD test check. This mixture had a 5-day BOD of 220-240 ppm. Constant volumes of the standard mixture were made at concentrations of 100 ppm for each of the ship's chemicals. In addition, the ability to oxidize these materials with chlorine was determined. Simultaneous samples were set up of each compound. A control sample and one which had a concentration of 35 ppm chlorine were tested. The results are shown in Table 9. Five of the compounds showed high levels of BOD_5 activity in concentrations of 100 ppm and none were oxidized by chlorine at levels of 35 ppm. It can be assumed that any one or all of these compounds were present in the waste system influent at any time during the day due to the around the clock operation of the ship.

A laboratory program was then initiated in order to determine a method for oxidation of the soluble BOD portion in the system effluent. In the interests of

TABLE 9. EFFECT OF CHEMICALS IN GERIG INVENTORY ON GLUCOSE/GLUTAMIC ACID BOD

No.	Chemical	ppm	No Cl_2		35 ppm Cl_2	
			BOD_2	BOD_5	BOD_2	BOD_5
1.	Laundry Detergent A	100	147	150	138	—
2.	Pine Oil A	100	197	Depl.*	220	Depl.*
3.	Solvent Degreaser (Chlorinated Hydrocarbon)	100	376	Depl.*	210	Depl.*
4.	Descaler	100	40	110	6	150
5.	Solvent/Detergent	100	Depl.*	Depl.*	Depl.*	Depl.*
6.	Paint Brush Cleaner	100	140	200	180	—
7.	Pine Oil B	100	Depl.*	Depl.*	Depl.*	Depl.*
8.	Laundry Detergent B	100	Depl.*	Depl.*	Depl.*	Depl.*
9.	Toilet Cleaner	100	85	150	150	—
10.	Combination 1-9	100	Depl.*	Depl.*	Depl.*	Depl.*
11.	Glutamic Acid/ Glucose**	—	140	210	—	—

*Depl. (Depletion) samples = BOD > 500 ppm

**A glutamic acid/glucose mixture was used as a check on the BOD procedure. BOD_5 of this solution should be 220-240.

economic and operation practicality, the following factors were considered to be of prime importance in the selection of soluble BOD reduction methods:

1. Environmental acceptability.
2. Safe for shipboard storage and handling.
3. Economic feasibility.
4. Require minimal system modification.

The following physical and chemical methods were tried in the laboratory or in the system with negative or insignificant results:

	% Reduction - Sol. BOD
Chlorine (up to 100 ppm)	0
Chlorine and elevated temp. (140°F)	0
Increased aeration efficiency (air or oxygen) (Table 10)	0
Potassium permanganate (Table 11)	0 (1)
Ozone (Table 13)	50 (2)
Hydrogen peroxide (Table 14)	0 (3)

(1) Apparent successful reducation was shown to be due to toxicity to BOD seed organisms. When $KMnO_4$ was completely neutralized before setting up the BOD, it was found to have no effect under the conditions tested (Table 12 and Figure 18).

(2) Ozone was ruled out for reasons of possible toxicity problems in the close quarters of the hold, length of required holding time, and expense of equipment.

(3) Hydrogen peroxide was not completely ruled out. Negative results were due to seed inhibition but there was no opportunity to neutralize the residual H_2O_2 and retest. Stable, high concentration mixtures are available.

On the basis of this lab program, it was determined that the soluble fraction of Gerig influent could not be oxidized within the limits of the above ground rules by any conventional chemical treatment known to investigators.

It was then decided to look at the feasibility of BOD reduction with activated carbon. A bench test was performed in which 1000 ppm of powdered activated carbon (DARCO S-51) was added to the coagulated influent (EC cell effluent) and allowed to precipitate. The BOD of the filtrate was measured before and after contact and showed no reduction due to carbon contact under these conditions. A laboratory column was then set up using 8 x 20 mesh granular activated charcoal (DARCO). Preliminary results are shown in Table 15. On the basis of previous information from the literature and the preliminary laboratory data, a

TABLE 10. EFFECT OF AERATION ON BOD_5 REDUCTION IN GERIG EFFLUENT

Effluent Sample Number	Aeration Time	Res. Chlorine (ppm)	BOD_5 (ppm)
1	0	68 ppm	340
1	30 min	68	220
1	60 min	68	300
2	0	42	340
2	30 min	42	340
2	60 min	42	340

EFFECT OF OXYGENATION ON BOD_5 REDUCTION IN GERIG EFFLUENT

Effluent Sample Number	Oxygenation Time	Res. Chlorine (ppm)	BOD_5 (ppm)
1	0	48	145
1	30 min	42	160
2	0	28	245
2	30 min	26	245

TABLE 11. EFFECTS OF POTASSIUM PERMANGANATE ON SYSTEM EFFLUENT BOD_5

Date	Sample Designation	pH	Residual Chlorine ppm	BOD_2 ppm	BOD_5 ppm
5-29-71	Effluent "C" - 1	-	-	-	140
5-29-71	Effluent "C" +25 ppm $KMnO_4$	-	-	-	160
5-29-71	Effluent "C" +50 ppm $KMnO_4$	-	-	-	140
5-29-71	Effluent "C" 100 ppm $KMnO_4$	-	-	-	115
5-29-71	Effluent "C" 250 ppm $KMnO_4$	-	-	-	70
5-29-71	Effluent "C" 500 ppm $KMnO_4$	-	-	-	33
5-29-71	Effluent "C" -2	-	-	-	190
5-29-71	Effluent "C" +25 ppm $KMnO_4$	-	-	-	200
5-29-71	Effluent "C" 50 ppm $KMnO_4$	-	-	-	190
5-29-71	Effluent "C" 100 ppm $KMnO_4$	-	-	-	195
5-29-71	Effluent "C" 250 ppm $KMnO_4$	-	-	-	140
5-29-71	Effluent "C" 500 ppm $KMnO_4$	-	-	-	13
5-29-71	Effluent "C"	9.2	26	135	210
6-7-71	System Effluent +50 ppm $KMnO_4$	-	-	140	220
6-7-71	System Effluent 100 ppm $KMnO_4$	-	-	48	150
6-7-71	System Effluent 250 ppm $KMnO_4$	-	-	0	0
6-7-71	Std. Glucose/Glutamic Acid	-	-	150	190
6-7-71	Std. Glucose/Glutamic +25 ppm $KMnO_4$	-	-	0	0
6-7-71	Std. Glucose/Glutamic +50 ppm $KMnO_4$	-	-	0	0
6-7-71	Std. Glucose/Glutamic +100 ppm $KMnO_4$	-	-	0	0
6-7-71	Std. Glucose/Glutamic 250 ppm $KMnO_4$	-	-	0	0
6-7-71	Std. Glucose/Glutamic 500 ppm $KMnO_4$	-	-	0	0
6-8-71	System Effluent 0930	9.3	34	115	285
6-8-71	System +50 ppm $KMnO_4$	-	-	105	260
6-8-71	System 100 ppm $KMnO_4$	-	-	10	3
6-8-71	System 250 ppm $KMnO_4$	-	-	3	0

TABLE 12. SYSTEM EFFLUENT TREATED WITH $KMnO_4$ AT 37°C FOR 60 MIN. THEN NEUTRALIZED WITH SODIUM THIOSULFATE

Effluent Sample Number	$KMnO_4$ (ppm)	BOD_5 (ppm)
1	0	220
1	100	240
1	150	245
2	0	230
2	100	240
2	150	280
3	0	300
3	100	260
3	150	300
4	0	300
4	100	290
4	150	320

TABLE 13. EFFECT OF OZONE ON BOD_5 REDUCTION IN GERIG EFFLUENT

Effluent Sample Number	Ozone Exposure	Res. Cl_2 (ppm)	BOD_5 (ppm)
1	0 min (0 ppm)	45	300
1	10 min (73 ppm)	45	250
1	60 min (450 ppm)	45	160
2	0 min (0 ppm)	1	160
2	10 min (73 ppm)	1	110
2	60 min (450 ppm)	1	85

TABLE 14. EFFECT OF HYDROGEN PEROXIDE ON BOD_5 REDUCTION IN GERIG EFFLUENT*

Effluent Sample Number	H_2O_2 (ppm)	BOD_5 (ppm)
1	0	165
1	300	-
1	400	140
1	500	180
2	0	165
2	300	80
2	400	215
2	500	140
3	0	190
3	300	235
3	400	360
3	500	Depleted

*Dissolved O_2 for the seed conrols were higher at the end of the 5 day period than at the beginning. Un-neutralized H_2O_2 interfered with seed and reagents.

carbon column subsystem was developed for use aboard the Gerig. The column was installed to accept the clarified system effluent. Average suspended solids and BOD_5 values for this period are:

	BOD_5 (ppm)	Suspended Solid (ppm)	
System Influent	570	750	
Influent to Carbon Columns	158	47	
System Effluent	94	*53	(38)

*Several high values were obtained during system malfunctions (anerobiosis, carbon carryover). When these values are removed, the corrected average is 38 ppm.

Detailed data is shown in Table 16.

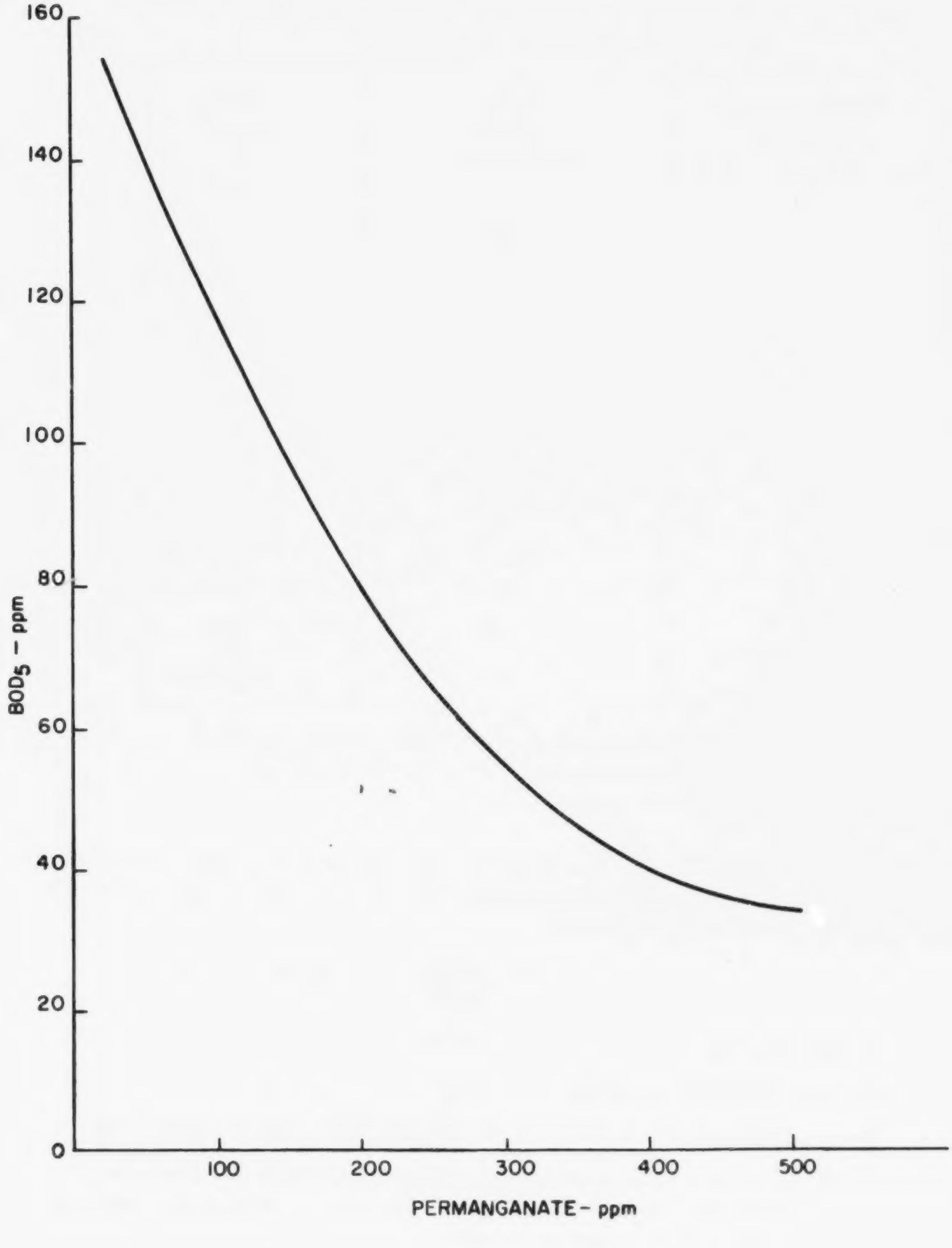


Figure 18. Effects of $KMnO_4$ on BOD_5 Due to Seed Poisoning

TABLE 15. RESULTS OF GRANULAR CARBON COLUMN TEST

Sample Designation	pH	Residual Chlorine (ppm)	BOD_2 (ppm)	BOD_5 (ppm)
System Effluent of 6-26-71	8.6	8.6	100	170
Column Effluent - 1 hour	9.2	0	32	46
Column Effluent - 1-1/2 hr	9.3	0	30	48
Column Effluent - 2 hours	9.3	0	30	42

Column Dimensions = 1" Diam x 6' Height
Flow Rate = 60 ml/minute

Analytical Notes

Residual Chlorine:

The HACH ortho-tolidine method was found to give low results when the strength of the waste was high. The phenylarsene oxide reduction technique gave reliable results over a wider range of waste strengths.

Suspended Solids/Turbidity:

Turbidity changes as a function of particulare characteristics as well as particle concentration, both of which vary widely in the influent and effluent. No consistent correlation was established between turbidity and suspended solids concentration.

Automated Analysis:

The chlorinated system effluent was routed through an automatic recording analyzer. Simultaneous readouts could be obtained for: residual chlorine, oxidation-reduction potential, pH, dissolved oxygen and turbidity. This proved to be an invaluable diagnostic tool for the monitoring of system performance. It is recommended that this type of monitoring be used routinely in system performance evaluation.

Data Interpretation:

In our studies it was found that the two-day BOD was reliable 60 percent of the five-day BOD. By use of the dissolved oxygen probe, it was possible to

TABLE 16. RESULTS OF FULL SCALE CARBON COLUMN OPERATION

Date	Sample Time	Influent		Influent to Column		Effluent from Column		Remarks
		BOD_5 (ppm)	S.S. (ppm)	BOD_5 (ppm)	S.S. (ppm)	BOD_5 (ppm)	S.S. (ppm)	
7/14	1100	440	1512					
	1310			230	34			
	1415					50	20	
7/15	0830	520	1570					
	0900			160	27	60	2	
				280	43	60	20	
7/16	0810	280	1175					
	0830			150	41	160	12	
				150	26	100	16	
7/17	0810	220	500	120	26	90	55	
	1330			130	20	80	6	
7/18	0900	360	1020	120	38	70	17	
				205	54	70	24	
7/19	1100			80	50	60	15	
	1300	400	580					
	1400			170	66	50	28	
7/20	0800			130	45	60	25	Coliform in effluent "too numerous to count"
	0915					70	30	
	1015	600	1770					
	1400			210	45	80	60	

TABLE 16. RESULTS OF FULL SCALE CARBON COLUMN OPERATION (Continued)

Date	Sample Time	Influent		Influent to Column		Effluent from Column		Remarks
		BOD_5 (ppm)	S. S. (ppm)	BOD_5 (ppm)	S. S. (ppm)	BOD_5 (ppm)	S. S. (ppm)	
7/21	0800	120	420					
	0800			65	24			
	0840					30	30	
7/22								Column fluidized at high flow rate to correct channeling. Done on basis of 7/16-17 BOD_5 which indicated performance degradation which in fact did not occur.
7/23	0810			130	51			
	1200	500	580					
	1330					70	50	
	1430					90	144	High solids are carbon. Evidently, a result of previous days flushings.
7/24								Sludge recycle pump failed (approx. 3000 hrs.) resulting in septicity. Configuration change to add chlorination downstream of carbon column and provide aerated water to column.
7/25								
7/26	9815	340	460					
	0820			120	14	40	40	
	1300			120	40	50	95	
	1500			140	20	90	60	

TABLE 16. RESULTS OF FULL SCALE CARBON COLUMN OPERATION (Continued)

Date	Sample Time	Influent		Influent to Column		Effluent from Column		Remarks
		BOD_5 (ppm)	S. S. (ppm)	BOD_5 (ppm)	S. S. (ppm)	BOD_5 (ppm)	S. S. (ppm)	
7/27	0830			120	20	30	45	
	1100	720	640					
	1230			220	76	30	18	
	1445			220	48	70	44	
7/28	--	-	490					
	0830			190	75			Aeration of column broke down due to failure of ship's air supply. Column went septic. Was corrected.
	1430					220	168	
7/29	--	340	390					
	0830			100	87	60	59	
	1345			50	57	70	75	
7/30	0845			160	56	110	40	
	1240	330	230					Effluent odoriferous. Suspect either aeration of chlorine feed malfunction.
	1400			230	53	110	66	
8/1	0825			110	56			
	0845					140	61	Effluent odoriferous. Effluent chlorine pump malfunction. Corrected
	1245	250	287					
	1400			230	96	130	50	
8/2	0940			130	68	150	200	Effluent septic due to chlorine pump and PSG failure.
	1410	840	456	230	70	150	106	

TABLE 16. RESULTS OF FULL SCALE CARBON COLUMN OPERATION (Continued)

Date	Sample Time	Influent		Influent to Column		Effluent from Column		Remarks
		BOD$_5$ (ppm)	S. S (ppm)	BOD$_5$ (ppm)	S. S. (ppm)	BOD$_5$ (ppm)	S. S. (ppm)	
8/5	1300	1200	-					Effluent septic due to chlorine pump and PSG failure.
	1400			200		200		
8/7	1130			190	-	200	-	Effluent odoriferous. Everything working.
	1215	1200	-					
	1420			190	-	200	-	
8/8	0820			130	-	50	-	
	1210	360	-					
	1410			220	-	70	-	
8/9	0835			115	-	60	-	
	1225	990	-		-			
	1410			80	-	70	-	

significantly decrease laboratory time by reading two-day BOD's without having to increase the number of samples set up. (Table 17).

TABLE 17. COMPARISON OF TWO-DAY AND FIVE DAY BOD DATA

Sample Designation	BOD$_2$ ppm	BOD$_2$ ppm
System Influent	160	260
System Influent	430	620
System Influent	310	450
System Influent	160	500
System Influent	200	260
System Influent	540	1020
System Influent	135	235
System Influent	460	770
System Influent	130	300
System Influent	280	380
System Influent Average	281	479
$\frac{BOD_2}{BOD_5} \times 100 = 59\%$		
System Effluent	77	110
System Effluent	150	390
System Effluent	90	185
System Effluent	180	260
System Effluent	170	240
System Effluent	170	220
System Effluent	140	215
System Effluent	60	100
System Effluent	110	155
System Effluent	70	100
System Effluent Average	122	197
$\frac{BOD_2}{BOD_5} \times 100 = 62\%$		

Sample Preservation

Samples were collected in plastic containers and refrigerated immediately. They were then transferred, in ice, from the ship to the laboratory. All samples were analyzed within 24 hours of collection.

C. Evaluation - Mechanical/Electrical Performance

Mechanical and electrical reliability are of more immediate importance to the marine engineer and ship operator than effluent quality. The system developed for this program is comprised of mechanical and electrical components of only moderate complexity and are of the type easily maintained by a ship's engine room crew at the apprentice level of skill with the aid of a simple manual.

The components selected for the system, as a whole, proved to be reliable for the application; pumps, valves, motors, electrical devices, such as timers, relays and switches, operated in the marine environment with no problems. Certain selected devices did malfunction, resulting in selection of more reliable components which were subsequently proven by many hours of operation; these are described in more detail in the following.

Wear rates, particularly for pumps, were established and proved to be superior to those component used in similar applications aboard the Gerig.

As part of the system evaluation, it became apparent that reduction of the numbers of parts could be achieved. These are included in the recommendations.

Electrocoagulation Cell

The electrocoagulation cell accumulated 750 hours of operation prior to need for replacement of the steel plates. This is equivalent to the processing of 225,000 gallons without replacement of coagulant. The need for replacement was determined when the iron output of the cell decreased below the objective of 70 mg/1. Examination of the plates removed indicated that 210 of the initial 271 pounds were consumed. The elapsed time between plate replacement can easily be increased by thickening the plates. This has been proved to be true on subsequent tests on other programs.

Operation of this cell with sanitary flushing waters ranging from fresh to seawater was accomplished with no difficulty in maintenance of the constant applied current to the cell. Voltage required to maintain 100 amperes ranged from 3 to 10 volts.

Teardown of the cell at plate replacement time revealed that deposited solids remained in most of the horizontal flow passages such that flow passages had become narrow channels.

Several conclusions may be drawn from the teardown. The simple horizontal arrangement of consumable plates periodically exposed to low pressure air flush, to dislodge any solids, did not perform the total clean out function; however, without air flush, complete blockage would be incurred within a short period. Further development of the electrocoagulation cell design requires a better mode of solids removal possibly by reorientation of the plate assembly and more positive scrubbing. Periodic (once a week) clean out by an acid flush has proved to be an effective clean-out technique on later designs.

Design of the sealed cell with provisions to safely conduct foam and hydrogen gas from the operating compartment operated without incident.

Pump Grinder

The pump-grinder performed the primary function of comminution of solids and flow delivery with no maintenance required until 1350 hours of operation. Comminution consistency in particle size was generally colloidal with nothing exceeding 0.25 inch as determined in the total suspended solids measurements made on the pump discharge effluent.

Replacement of the synthetic rubber stator of the Moyno ® (Robbins and Meyers Co. FS44) progressive-cavity pump was required at 1350 hours. Failure to deliver flow was observed and attributed to wear of the stator as accelerated by the high sand content of the sanitary flush water. It was not necessary during the sea trials to drain and clean out the base of this unit for removal of items deliverately permitted to settle — such as cutlery, bolts, and other inert obejects.

Upflow Clarifier/Concentrator

The upflow clarifier is the only component in this system whose primary function would be affected by sea-state conditions. Maintenance of the sludge underflow which depends upon gravity forces for solids settling was not adversely affected by vessel motion at anytime in the test period. Supernatant total suspended solids measurements were made on all samples obtained under the entire gamut of climatic conditions.

At 340 hours of operation, it was necessary to replace the lower bushing of the central downcomer stirrer due to binding. The lower bushing removed was a Cutless ® brass sleeve with neoprene molded insert, typical of units used on propeller shaft hull penetrations. In this application, sufficient sludge accumulation impeded lubrication of the neoprene insert. A straight substitution of a Teflon ® bearing prevented any repetition of the problem during the subsequent 4000 hours of operation.

The hydrodynamic stability of the upflow clarifier proved to be troublesome during early phases of the program. The balance of influent versus effluent and sludge withdrawal rates is critical but can and was achieved. A reliable, maintenance free, sludge level detector would be extremely useful to insure preservation of the hydraulic balance, and would increase the capacity of the waste treatment plant by permitting higher flow rates. Earlier in the program, sensors of the optical, sonic, and viscous type, were tried with little success.

Recent tests, not associated with this program, have established positively that the concentrator may be eliminated from the system with no reduction in sludge concentration. In fact, withdrawal of the sludge from the proper place in the blanket results in an increase in concentration up to three percent with a proportional reduction in incinerator load. Evaluation of a recently developed Viscometer ® for sludge level detection also shows considerable promise for control of sludge withdrawal.

Elimination of the sludge concentrator would remove one pump and associated plumbing and electrical connections from the system as well as reducing system weight and volume.

Carbon Columns

The activated carbon columns were implemented during the final month of test. The columns were a direct scale-up from laboratory bench scale. Three hundred pounds of activated carbon (Darco ® 8 x 35 mesh, Atlas Chemical Co.) were housed in four cylinders arranged such that flow was upward. It was found necessary to maintain a continuous flow through the carbon beds to prevent packing. By utilizing a recycle of aerated column effluent during slack periods, septicity of the column was precluded. The fine mesh carbon yielded a higher capacity and higher rate of absorption of organics than would a coarser mesh. Operated at 4.6 gallons per minute of upflow, the columns as sized should not require replacement for a minimum of three months. Replacement would entail removal of an individual column while operating with the remainder.

Power Supply

The power supply operated on 440 vac, 3-phase, and provided direct-current voltage to the electrocoagulation cell plates at a constant current level. The unit consisted of a three-phase, motor-driven variac, three-phase transformer, solid state rectification of each phase, and a solid state current control. Transitions in wastewater conductivity did not adversely affect the constant current control.

The single failure of the power supply occurred when a silicon rectifier shorted and caused overheating of the variac. Fuse protection was added to the variac output and low voltage transformer output to the rectifier bank.

Sensors

Control sensors in an automated system assume greater importance when they fail because of secondary system consequences. Since diverse sensor types were used to control functions in this system, some observations may be drawn concerning their reliability in this application:

1. Disphragm actuated switch: This type provided the most reliable level sensing in sewage and sludge vessels by virtue of a large contact area insensitive to build-up.

2. Conductivity probes: Sensors of this variety which seek to complete a conductive path through the liquid medium were adversely affected by spurious moisture paths on mounting plates in spite of protective sleeving.

3. Bubbler sensor: The switch sensing pressure changes for flowing air in response to level changes consistently clogged in the purging tube.

4. Sail switch: These sensors, sensing flow by exposing a paddle to the fluid medium, failed because of fragile supporting linkages.

Materials of Construction

In keeping with the development intent of this program, it was decided that the materials of construction for this system would depart from traditional marine materials. All the key tanks in the system were constructed from 5052 aluminum while the plumbing was rigid polyvinyl chloride (PVC).

Examination of the aluminum tanks, which were uncoated internally, revealed absence of significant corrosion due to seawater. The solvent welded plastic piping, which remained unpainted but otherwise received no special handling, proved extremely reliable in the marine environment. A consideration not to be lightly regarded is the relative freedom from solids accumulations observed when sludge pipes were disassembled. This has not been true with galvanized steel threaded pipe used in similar applications.

Chemical Metering Pumps

The liquid chemical metering pumps utilized to supply the sodium aluminate flocculant aid, and hypochlorite solution were single-acting adjustable disphragm types. Priming of the suction and delivery flexible tubing was maintained with ball check valves. A screen mesh filter was fitted on the suction tube. These units did not perform reliably. Maintenance of these pumps was required at frequent intervals. Loss of the initial calibration or prime was incurred due to crystal buildup on the check valves. Since reliable operation of the metering pumps is a must, alternate hardware or metering techniques are required.

A more reliable pump type, produced by Everchlor ®, has subsequently been evaluated and found to be reliable.

Sewage Pumps

The progressive-cavity pumps used to pass wastewater and sludge performed reliably with minimum maintenance required. Of the system total of nine of these pumps, only the unit in the pump-grinder required stator replacement after 1350 hours of handling gritty influent. The single constraint on reliable life of these pumps in sewage handling service would appear to be a precaution against operating these pumps dry.

D. Analysis-Economic

Introduction

Although the shipboard waste treatment system installed on the Gerig was an engineering prototype and not necessarily representative of a final commercial design, the Gerig experience and later design activity by General Electric permit a projection of the operating cost of the process to a typical ship owner.

Costs have been normalized to exclude items related solely to the testing program while adding on costs related to normal long-term operation. The resulting cost figures approximate the cost of operating a permanently installed, quantity produced system by 2500 GPD capacity.

Cost Assumptions

Several key assumptions had to be made in estimating the economics of the treatment system since the nature and duration of the demonstration did not yield sufficient first hand experience. Estimates on equipment life expectancy and overhaul requirements were based on conservative commercial practice in lieu of long term operating experience. Although the prototype at times required manual control and monitoring of certain operations, the exclusion of additional manpower cost for normal system operation was based on successful experience with complete automatic control on other General Electric treatment systems.

Since carbon adsorbtion was added late in the demonstration program, insufficient operating experience is available to accurately predict carbon bed replacement frequency. However, on the basis of available operating experience and prior research (reference 7), an efficiency of 0.25 pound BOD per pound of carbon was assumed for this operating range with the carbon column aided by normal biological activity in the columns.

The actual cost of system installation onboard Gerig is not available. Sewage collection lines were already present and hardware installation was performed as part of a general ship overhaul.

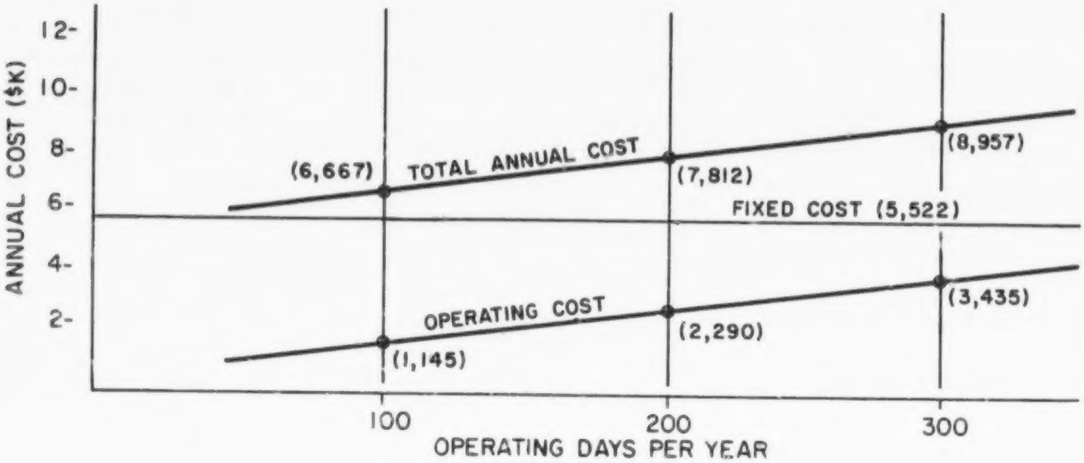
Costing Method

All capital and replacement costs were reduced to an average annual cost over a twenty year system life. A straight-line amorization of initial purchase price was made. Since interest rate will vary with type of owner and time of purchase, the cost of money was excluded. An estimate of annual overhaul expense is shown, although actual overhaul may occur at a lesser frequency.

The system was assumed to be operated at full rated capacity, but the number of days per year of operation was parameterized due to the large difference among ships' operating time in coastal waters (see Figure 19).

Annual Cost

The complete system including incinerator and carbon adsorption columns would have an initial purchase cost of $36,900 if produced in quantity. Installation is estimated at $55,000 giving an initial total cost of $91,900. This initial cost and periodic overhauls would give a $5,522 per year average fixed cost over a twenty year life. To this fixed cost must be added a $11.45 per day operating cost. Operating cost is comprised primarily of carbon replacement, EC cell plate replacement, and incinerator fuel. Based on these costs, a system operated for 200 days/year would have a total annual cost of $7,812 (see Tables 18 and 19). Without carbon adsorption, this cost would be reduced 12 percent to $6867.



COST ASSUMPTIONS

- Routine operating and servicing performed by normal ships crew compliment.
- Cost of installation 55$K.
- Utilization of existing power and air supply.
- Bulk purchase of consumables.
- Cost of money excluded.
- 20 year system life.
- 2500 gal/day average waste water flow.
- Sea water heads.
- Quantity production of system.

Figure 19. Projected Annual Cost of System Operation

TABLE 18. WASTE TREATMENT SYSTEM FIXED COSTS

Maintenance Items		Estimated Material Cost
Pumps		$ 900
Incinerator shell		5,000
Electric motors		250
PSG overhaul		300
Blower		500
Controls and power supply		2,000
		$8,950
$8,950 ÷ 20 year life = annual cost $447		
Annual Overhaul Labor:		
80 hours x $6/hr.		480
Amortization:		
System purchase price —	$ 36,900	
Installation	55,000	
	$ 91,990	
$ 91,900 ÷ 20 year life = annual cost		$4,595
Total annual fixed cost		$5,522

TABLE 19. WASTE TREATMENT SYSTEM OPERATING COSTS

Item	Consumption Rate	Unit Cost ($)	Daily Cost ($)
Electric power	7.2 kwh/day	.015	1.08
Chlorine solution	5 gal/day	.250	1.25
Floc aid	2.5 lbs/day	.230	.57
Incinerator fuel	32 gal/day	.100	3.20
EC cell plates	600 hr/set	87.000	1.30
Activated carbon	12.5 lb/day	.260	3.25
Maintenance	4 hrs/mo	6.000	.80
	Cost per day operation		$ 11.45

Comparative Economics

The economic feasibility of this process depends not only on the ship owner's ability to pay, but on the cost of alternative approaches. Since holding tanks are a frequently considered alternative for shipboard waste disposal, the comparative costs of this alternative were developed and are compared on Figure 20.

Costs for holding are based on comparable ship type and crew size. The tank was sized for seven days maximum hold and 45 gpm pump out. Twenty year amortization of initial cost is assumed. A labor cost of $6 per hour is assessed for pier side connection.

Shore side disposal, the major operating cost, is parameterized to reflect its variable nature. At a cost of $2.50/KG, an average pump out cost on Lake Michigan (reference 8) the cost of treatment is 11 percent greater than that of simple holding.

It should be recognized that the shore cost of treatment is highly variable (reference 9) and if a vessel must resort to barging or trucking water wastes, the cost of transfer and treatment can increase by a factor ten. In view of the far greater operating flexibility of the treatment system and the holding tank's dependence on an uncertain availability and cost of shore side disposal, the apparent small cost penalty incurred by treatment can be easily offset.

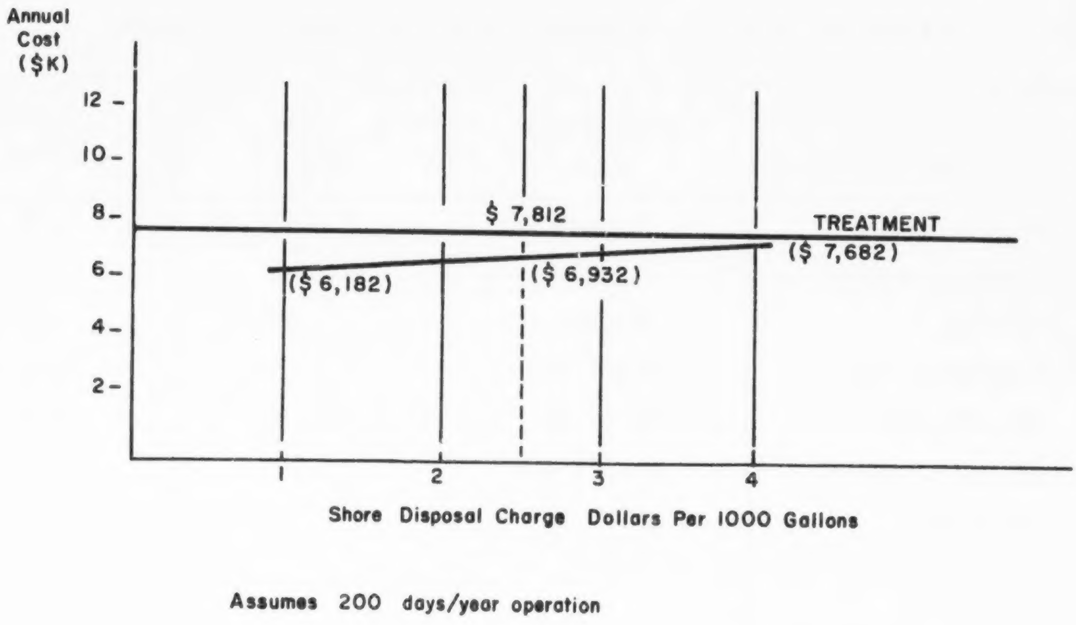


Figure 20. Comparitive Cost of Treatment vs. Holding

SECTION VI

ACKNOWLEDGEMENTS

This program, which extended over a period of twenty-seven months, was accomplished by the dedication and cooperation of many individuals in government agencies and the contractor organization. Due to the numbers of these individuals only a few can be mentioned, however, the authors wish to express their sincere appreciation to all contributors.

The support of the project by the Office of Research and Monitoring, Environmental Protection Agency and the help and guidance provided by K. Jakobson, Project Officer, is acknowledged with sincere thanks.

The officers and crew of the U.S. Army Corps of Engineers vessel Gerig were especially helpful during onboard operations and in circumventing many communication and logistics problems associate with working on board a ship at sea. Capt. R. Boltin and Chief Engineer J. Owens were key people to this successful operation.

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The Cincinnati, Ohio Office of the Environmental Protection Agency provided invaluable work and equipment for water chemistry analysis during a major part of the sea trials. Mr. E. Raabe provided expert training for proper analytical technique to General Electric personnel.

Dr. Brauer and the Wrightsville Marine Bio-Medical Laboratory provided laboratory facilities at no cost during operations in North Carolina. Their assistance is greatly appreciated.

The development, design, analytical work, and sea trials were performed by a team from the General Electric Company, Re-entry and Environmental Systems Division, the key members of which were J.C. White, Program Manager; P. Shelley, Project Engineer; A. Bryce, Project Biochemist; D. Cheater, Biochemical Analysis; E. Darrah, F. Milotich, J. O'Donnell, Ships Crew.

SECTION VII

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SECTION VIII

GLOSSARY

BOD - Biochemical Oxygen Demand

BOD_2 - Biochemical Oxygen Demand (2-day Analysis)

BOD_5 - Biochemical Oxygen Demand (5-day Analysis)

COD - Chemical Oxygen Demand

Colif. - Coliform (bacteria)

Col./100 ml or MPN Col./100 ml - Most probable number of colonies (of bacteria) per 100 milliliters (of sample)

GPD - Gallons per day

Depl. - Depletion

D.O. - Dissolved Oxygen

Eff. - Effluent

Inf. - Influent

IOD - Immediate Oxygen Demand

JTU - Jackson Tubidity Units

mg/l - Milligrams per liter (same as ppm)

ORP - Oxidation-Reduction Potential

ppm - Parts per million (by weight)

PVC - Polyvinylchloride (plastic)

Res. Cl_2 - Residual chlorine

Sol. BOD - Soluble BOD

S.S. - Supsended solids

TOD - Total oxygen demand

TOT BOD - Total Biochemical Oxygen Demand

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SECTION IX

APPENDICES

A. Component Development Report for the Watercraft Waste Treatment System

B. Summary of Gerig SWTS Test Data

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INTRODUCTION

The General Electric Company, Re-entry and Environmental Systems Division (RESD) was awarded Contract 14-12-522 to develop, build, and test a prototype shipboard waste treatment based substantially on proposals submitted to the FWQA in December, 1968 and January, 1969. The contract was initiated in May, 1969 and the component development proceeded in accordance with the *Program Plan – Shipboard Water Pollution Control Project*, (Reference 1).

The objectives of this contract which encompassed 22 months are: 1) develop an operating shipboard waste treatment plant for large vessels, 2) demonstrate success in meeting high waste treatment standards, 3) operate for a test period aboard a ship, and 4) perform an evaluation of the function and economy of the system. Intensive development effort was to be spent on electrocoagulation as a technique for electrochemically generating flocculants and treating wastes.

The performance objectives established for the prototype system have evolved since the inception of the project. The resulting effluent parameters are as follows:

Parameter	Objective
Biochemical oxygen demand	$<$50 ppm
Total suspended solids	$<$50 ppm
Coliform bacteria	240 MPN/100 ml

Waste treatment components and systems had been the object of advanced studies and development contracts in the G-E Co. laboratories over the past decade. The advanced waste treatment techniques studied included electrochemical treatment of sewage, and based on the exhibited potentials G-E RESD sought the opportunity to design and build such a shipboard system.

The prototype system was designed to meet the requirements imposed by a ship, because compelling reasons exist to preclude using the typical, land-based treatment process. Therefore, the prototype system described in this document is not an adaptation of the conventional treatment facility. The watercraft plant must operate under constant ship motion, with waste waters having the salinity values of fresh to seawater, and with a hydraulic loading having significant peak loadings. The plant must also have minimum complexity, weight, and volume to be acceptable for shipboard. The electrocoagulation approach was selected by the General Electric Company because, unlike biological treatment systems, it would be relatively insensitive to the wide fluctuations in influent composition and temperature that can be expected aboard a watercraft. In addition, an electro-chemical system can not be poisoned by cleaning agents, acids, or bases.

The following description provides a brief introduction to the watercraft-plant system concept, functionally shown in Figure 1. The components and the functions described individually should not be construed to place singular emphasis on any single component or function. To understand the system rationale it is necessary to grasp the significance of component interdependence. Taken one step further, it is likely that several of the components could be combined in an advanced system, even though the functions accomplished in the prototype would still be required.

As shown in Figure 1, the sewage of culinary, wastewater, laundry and sanitary origin is piped to the Pump-Grinder, which provides an aerated sewage storage capacity that smooths out process operating cycles, that grinds the sewage solids, and that establishes the constant throughput flow to the treatment cell. In the Electrocoagulation Cell, ferrous ions are electrochemically generated by applying a d-c potential to steel plates arranged in parallel. The comminuted sewage and waste water are then pumped in between the steel plates. Coagulation of the ferrous ions and sewage is enhanced by providing sufficient transport time in the cell.

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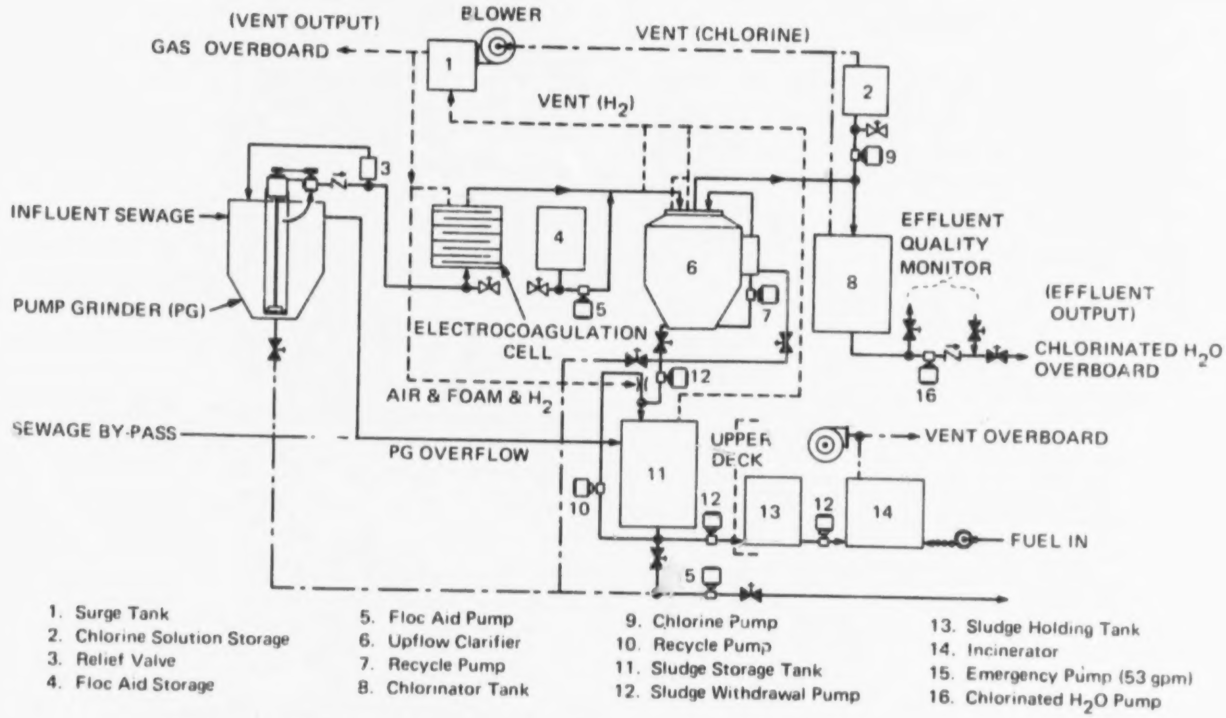
(VENT OUTPUT)
GAS OVERBOARD
BLOWER
VENT (CHLORINE)
VENT (H2)
INFLUENT SEWAGE
PUMP GRINDER (PG)
ELECTROCOAGULATION CELL
AIR & FOAM & H2
SEWAGE BY-PASS
PG OVERFLOW
EFFLUENT QUALITY MONITOR
(EFFLUENT OUTPUT)
CHLORINATED H2O OVERBOARD
UPPER DECK
VENT OVERBOARD
FUEL IN
1
2
3
4
5
6
7
8
9
10
11
12
13
14
16
1. Surge Tank
2. Chlorine Solution Storage
3. Relief Valve
4. Floc Aid Storage
5. Floc Aid Pump
6. Upflow Clarifier
7. Recycle Pump
8. Chlorinator Tank
9. Chlorine Pump
10. Recycle Pump
11. Sludge Storage Tank
12. Sludge Withdrawal Pump
13. Sludge Holding Tank
14. Incinerator
15. Emergency Pump (53 gpm)
16. Chlorinated H2O Pump

Figure 1. Watercraft Waste Treatment System Schematic

Flocculation of these particles to form larger aggregates capable of separation by sedimentation is accelerated by the rapid mix of the agitator in the Upflow Clarifier. The sludge is transferred and concentrated by pumping it into the sludge storage tank where it is periodically withdrawn for incineration. The clarified effluent from the clarifier is disinfected and pumped overboard without any harmful effects to the body of water in which the ship is travelling.

In summary and based heavily on the data presented in this report and on those data from the many tests not presented here because of space limitations, it is concluded that physical-electrochemical treatment is the best solution to waste treatment on ships. Conclusive data on alternate systems performance are not readily accessible, but inherent advantages of the physical-electrochemical may be postulated. Unlike aerobic treatment the prototype plant is capable of rapid start and shutdown, is free from effects of salinity and hydraulic gradients, and permits significant size reductions. Continued development of the prototype concept is recommended and should be concentrated on simplification and component performance improvements.

COMPONENT DEVELOPMENT

DEVELOPMENT BACKGROUND

It was noted in the introductory statements to this report that the Re-entry and Environmental Systems Division proposed to develop a watercraft waste treatment system based on experimental work performed at the General Electric Research and Development Laboratory. Sufficient laboratory scale results existed to warrant further development of shipboard components.

Based on a waste treatment process utilizing electrocoagulation and solids separation, key components of a system were identified. The project program plan (Reference 1) then established a component development schedule summary which is given in Figure 2. Such a plan does result in a system comprised of individual components because development units were subsequently used at the system level. Therefore, there exists ample opportunity for combining components and for decreasing the volume of this first system in later configurations.

In retrospect, it can be said that the resulting system was essentially designed from the ground floor up. A thorough review of existent test data and early test results at G-E RESD with electrocoagulation, required that company funds be allotted for basic cell development and characterization.

At the start of this project the solution to the problem of sludge disposal was to store it for convenient disposal later. This concept seemed viable at contract inception since incineration was straightforward. During the project, investigation revealed that sludge burning incinerators for shipboard were not generally available. Agreement was then reached with the FWQA to alter the project scope to include refurbishment of a government-furnished incinerator. The unit proved to be incapable of refurbishment. An incinerator is being developed with company funds and will be available for the shipboard demonstration.

PUMP GRINDER

All sewage generated on a ship is piped to the Pump-Grinder, which functions to provide storage volume, so that the operation of the system can be smoothed out into a fewer number of cycles and for purposes of comminution of solids into colloidal sizes for pumping into the Electrocoagulation Cell. Comminution of the solids in wastewater assures maximum particle surface area, as this is critical to the success of the coagulation process. Comminution also permits the use of small diameter pipe and minimum interplate flow passages, permitting in turn lower d-c voltage operation of the cell.

To achieve reduction of solids to less than 0.25 in. diameter, a developmental component built by the General Electric Company for the American Society of Civil Engineers under FWPCA Contract 14-12-29 was transferred to this project. This unit utilizes grinder technology accumulated by the General Electric Company in the manufacture of household and commercial grinders.

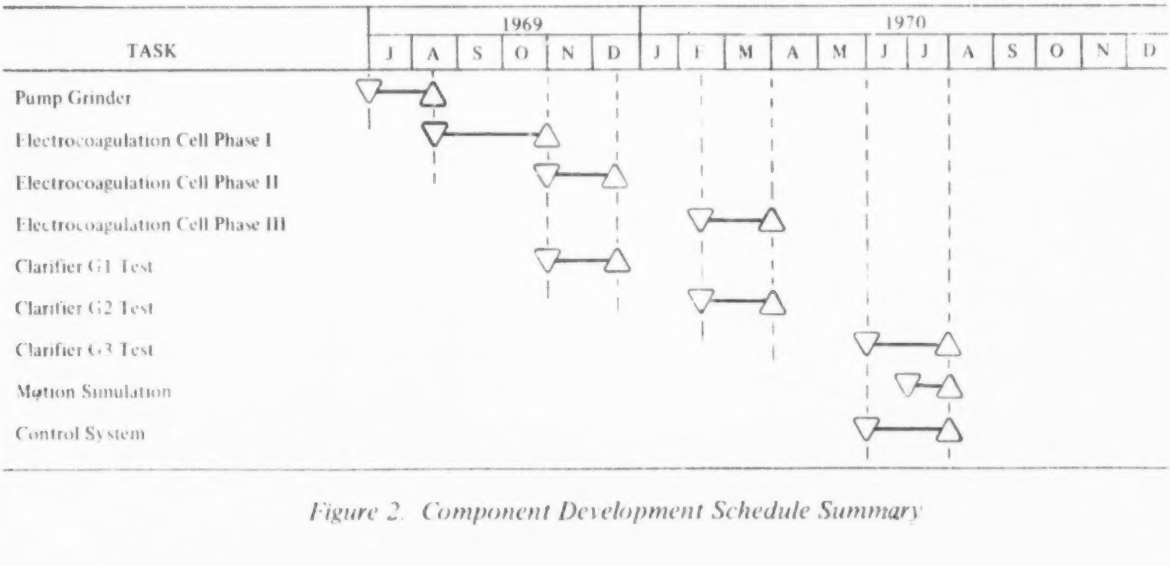

Figure 2. Component Development Schedule Summary

The unit, before modification, is shown in Figure 3.

A similar Pump-Grinder developed by G.E. Co. for the Combined Sewer Separation Project of the ASCE was successfully adapted for use in the watercraft application. The laboratory unit has been redesigned to accommodate three times the sewage capacity, has had new sealed bearings installed, has a new control system, and has incorporated upgraded components for operation in seawater. See Table 1. A duplicate unit was built to conduct an endurance test, and with the upgraded hardware, 1000 hours of sewage operation were successfully completed.

TABLE 1. PUMP GRINDER SPECIFICATIONS

Part	Characteristics and/or part number
Motor	General Electric Model 5KC47RG913U, 1 HP, 1725 rpm, capacitor start, single phase
Power	115 VAC, 10 a, 60 Hz
Pump	Moyno^R 1 S44 with rotary seal
Upper PG bearing	Sealmaster 64522-PS3 (L-12)
Lower PG bearing	Delco New Departure Z99R12

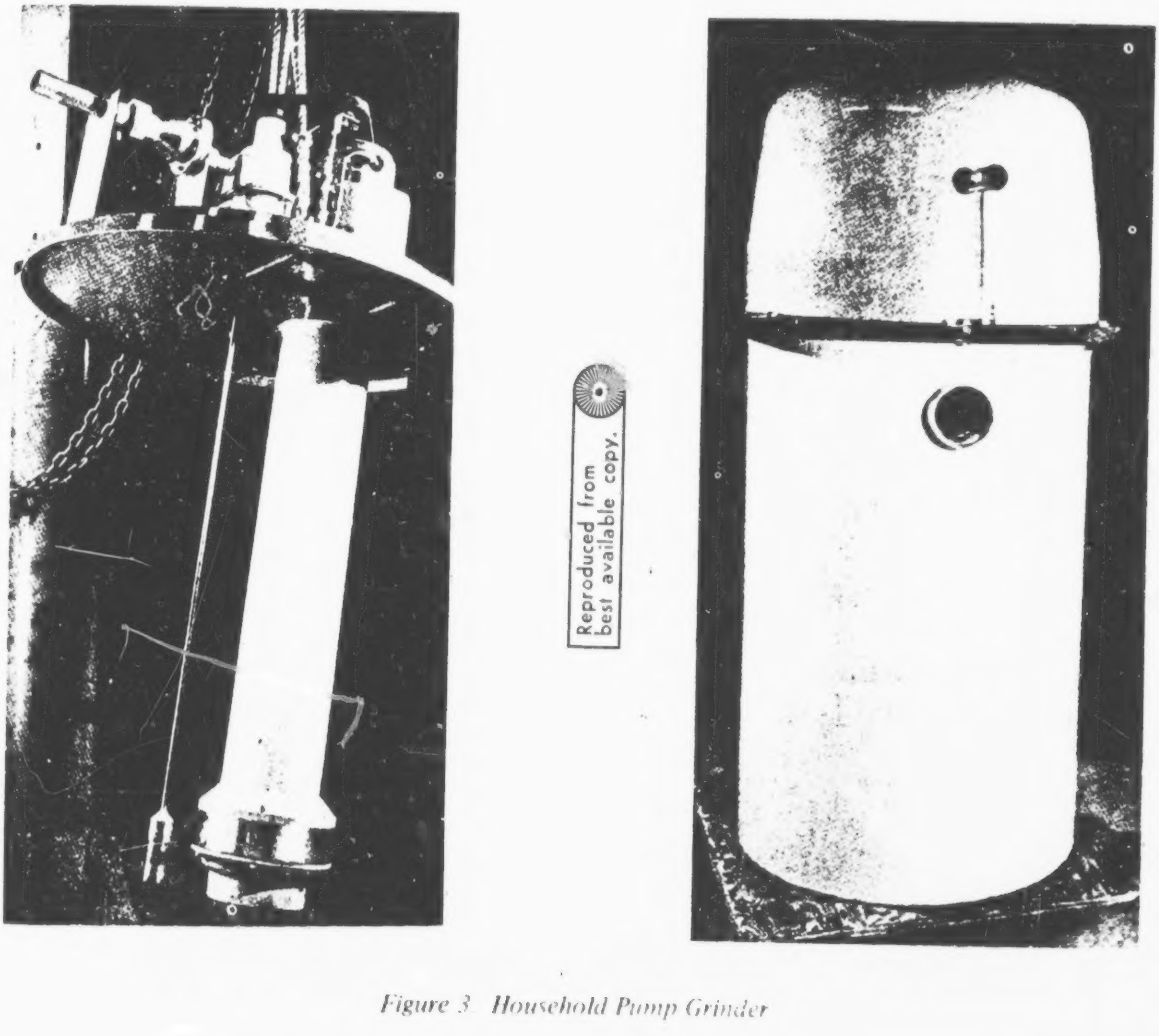

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Figure 3 Household Pump Grinder

CONSIDERATIONS IN ALTERING PUMP–GRINDERS

Use of the unit shown in Figure 3 was considered because the essential features of a shipboard Pump-Grinder already were present in this component, and project economy could be realized if tests of the altered Pump-Grinder in seawater were successful. The first unit was conceived as a solution to the peakloads generated in a typical household of four persons. The tank volume had a capacity of 55 gallons and a discharge flow of 15 to 11 gallons/minute for 0 to 35 psi. The use of a modified G-E Hotpoint commercial grinder in the configuration chosen assured that all sewage would be comminuted before discharge and that heavy objects would fall harmlessly to the bottom of the tank for cleanout at a later time.

The following paragraphs present the considerations and alterations made in adapting this hardware, as shown in Figure 4, for use in watercraft. The considerations made were on establishing flowrate, determining aerated storage volume, running an endurance test, and establishing emergency passages.

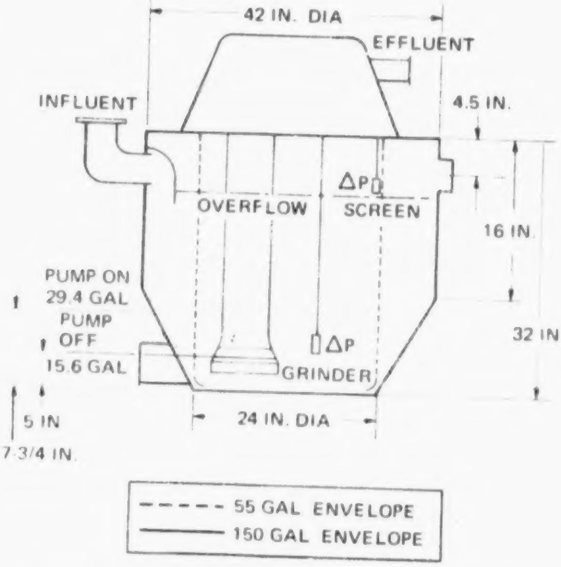

Figure 4. Watercraft System Pump Grinder

a. *Establishing Flowrate.* The Pump-Grinder utilizes a double-ended shaft AC motor which drives the inverted grinder flywheel directly and drives a progressive cavity pump through a belt drive. The key factors which are determined by the selected system flowrate are the required storage volume of the Pump-Grinder, the power and plate area required in the Electrocoagulation Cell, and, of paramount consequence, the volume of the Upflow Clarifier. Of the factors considered, the detention time of one hour in the clarifier, weighed against the increase in storage required in the Pump-Grinder if flowrate was reduced, caused a flowrate of 5 gpm and a clarifier volume of 300 gal to be selected as a suitable compromise. (See Figure 5.)

b. *Determining Aerated Storage Volume.* The Pump-Grinder tank volume was established by examining the hydrograph determined for the ship, Dredge Gerig, in the wastewater quality and flow survey performed in August 1969 (See Reference 2). The hydrograph is reproduced here as Figure 6. The peak-sewage-influent flow occurred at 1612. The method of data accumulation measured the effluent pump on/off cycles from the existent plant. An on/off cycle for this pump occurred when 80 gal was received. Table 2 presents the sewage accumulated in the peak period in tabular form. The system flowrate used to establish the total accumulation in the tank was 5 gpm.

To arrive at a suitable tank volume it is necessary to include an additional 79 gal since this is a surge influx which could, because of the measurement technique, be missed. Therefore, 150 gal capacity was selected.

c. *Running an Endurance Test.* A duplicate Pump-Grinder was fabricated with G.E. Co. funding and was subjected to extensive tests. No difficulty was encountered when plastic spoons, cloth and disposable diapers, sanitary napkins, sand, and filter cigarettes were processed. After 90 hours of test, excessive bearing noise was noted. Disassembly of the unit revealed that weepage of wastewater by the shaft seal into an unsealed bearing caused loss of lubricant and rough operation. Replacement of the lower bearing by a sealed bearing permitted 1000 hours of successful operation.

TABLE 2. CALCULATED PEAK FLOW TO PUMP GRINDER

Time	Time (minutes)	PG output in ΔT (gallons)	Input minus output (gallons)	Total Accumulation (gallons)
1612				
	9	45	35	35
1621				
	13.3	66.5	13.5	48.5
1634.3				
	9.85	49.25	30.75	79.25
1643.2				
	25	125	45	34.25
1708.2				
	24.3	121.5	41.5	
1732.5				

NOTES: Data is from Dredge Gerig survey (Reference 2).
Input volume was 80 gallons before pump-out.
The PG rate is 5 gal/min.

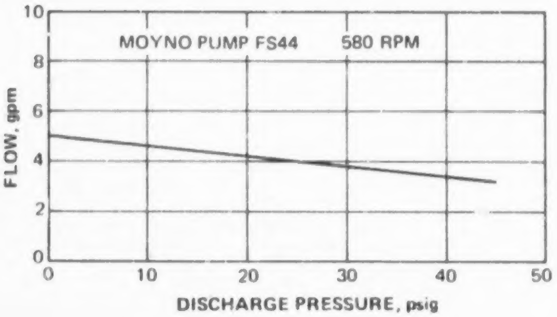

Figure 5. Pump Grinder Flow vs. Pressure

d.. *Establishing Emergency Passages.* An overflow sensor was incorporated so as to indicate influent sewage flow through the protective barrier screen and overflow pipe connected to the Sludge Storage Tank. This was an emergency provision to divert influent, in the event of Pump-Grinder overflow, directly into the sludge tank. An indication of overload of the sludge tank will cause pump out from this tank at the rate of 52 gpm. A relief valve and bypass line downstream of the pump provide protection against overpressure in the cell.

ELECTROCOAGULATION CELL

The primary function of the Electrocoagulation Cell is to generate ferrous hydroxide coagulant for waste treatment. This is done electrically by applying a d.c. voltage to mild steel plates. Electrocoagulation can be appreciated when the following features of the complete system are understood:

a. Startup and shutdown of the system is immediate because only flow and power need be initiated

b. Trained personnel are not needed or required to establish and reestablish system operation after shutdown.

c.. Constant current control assures independence of effects from wastewater salinity level.

d. Rapid but thorough exposure of sewage solids to the coagulant is inherent to the cell design.

e. Attendant reduction in contaminant level can be attributed to electrolysis and oxidation/reduction.

When a logically made comparison is made with chemical coagulation, electrocoagulation results in a shorter processing time and greater reduction of pollution contributing constituents in the effluent.

Experimentation in treatment of municipal wastes by electrocoagulation was reported by the General Electric Research and Development Center, Schenectady, N.Y. (R&DC), for a period

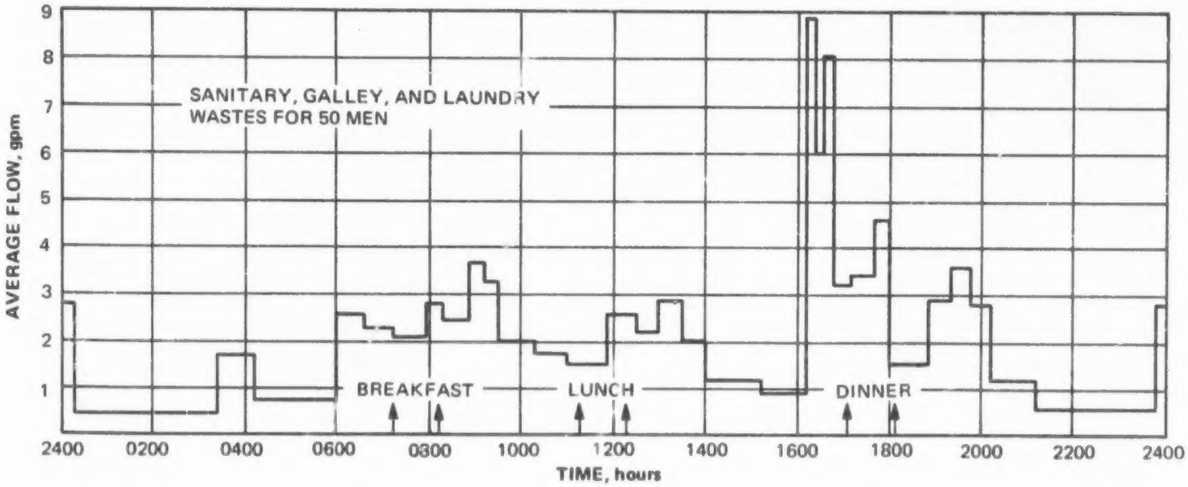

Figure 6. Wastewater Hydrograph in the Dredge Gerig

from 1966 - 1968. Sufficient test data were obtained to show that significant reduction in BOD, in total suspended solids, and in turbidity was achieved when jar test settling or centrifugation followed cell treatment.

A cell, reported in an R&D Center test report, and which was used for the batch treatment of four gallons of sewage is shown in Figure 7. A more advanced electrocoagulation cell used in field test is depicted in Figure 8. Examination of this photograph shows that the cell was open at the top and a series of skimmers were required to remove foam.

It was recognized that substantial engineering remained to transform these laboratory units into shipboard suitable components. The Statement of Work for the project directed, therefore, that major system development emphasis be devoted to optimization of the electrocoagulation treatment. It is quite logical, then, that initial development work was primarily engineering. The aspects of electrocoagulation studied included:

a. Cell plate geometry and wastewater flow paths,
b. Power requirements,
c. Foam and floatable disposal,
d. Safe gas venting, and
e. Solids accumulation removal.

The development plan for the electrocoagulation cell was conceived on the assumption that sufficient data existed to enable the design of a watercraft cell. A reassessment of this approach was required when initial tests at R&D with seawater wastewater yielded a floating floc. These poor results did not agree with results reported for the cell depicted in Figure 8. The reason for the gross performance difference became clear upon closer review of earlier R&DC data which was gained by doping municipal wastewater with common salt. For reasons explained fully in later text, sea water which contains magnesium, calcium, and potassium salts in addition to small percentages of others, drives the pH substantially below the optimum for ferrous hydrated oxide precipitation.

The upshot of these findings was a reevaluation of the content of the electrocoagulation cell development program. In view of the basic nature of these initial conclusions, GE Co. sponsorship of a plan to characterize the electrocoagulation cell with respect to critical parameters was obtained. Although not originally conceived as a task comprised of several building blocks, the

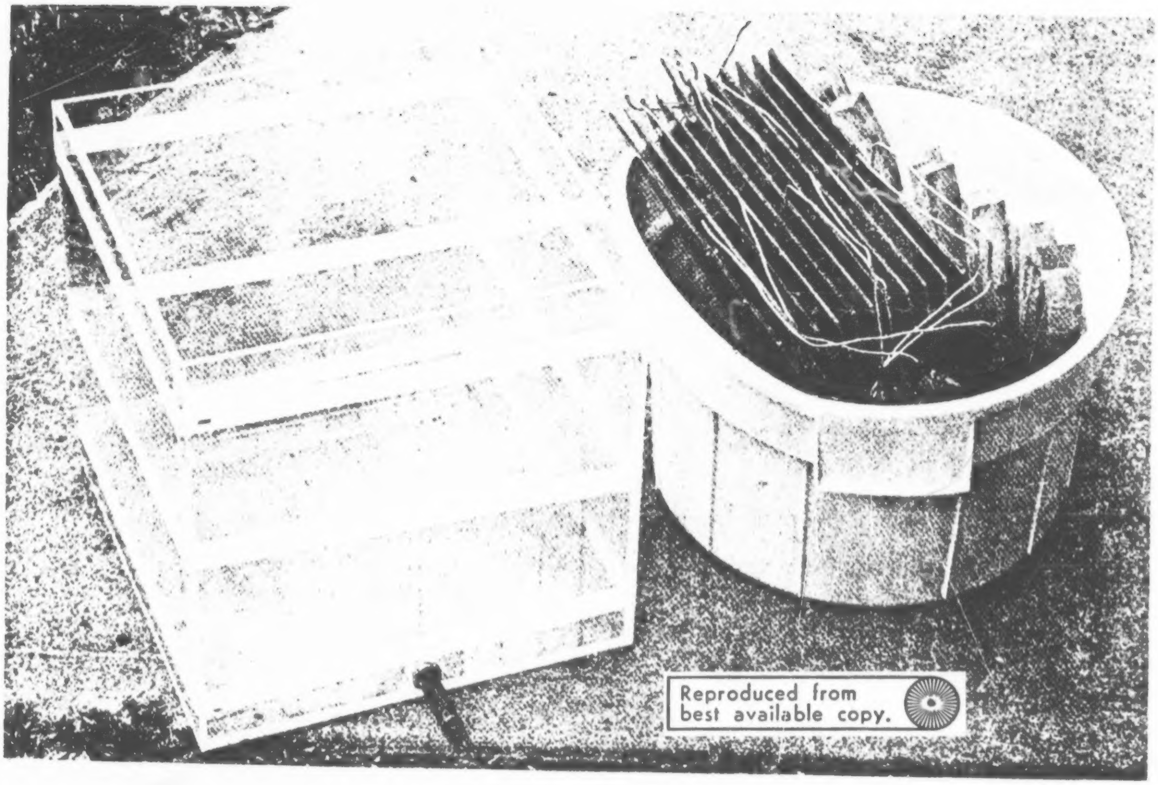

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Figure 7. R. and D.C. Electrocoagulation Cell for Batch Tests

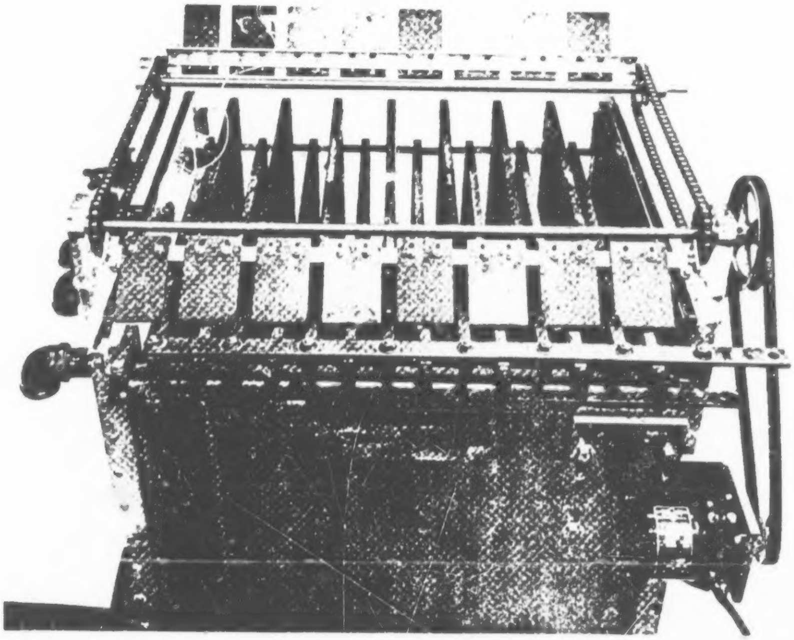

Figure 8. R. and D.C. Electrocoagulation Cell Used for Field Tests

development of a watercraft electrocoagulation cell was performed in three phases:

- Phase I. Characterization of the cell with a range of influents
- Phase II. Evaluation of flocculent aids in sea water
- Phase III. Biochemical performance with sewage

Electrocoagulation as a key feature of the prototype watercraft waste treatment system has conclusively proved its merits. Some of the important attributes of a watercraft system incorporating electrocoagulation are 1) rapid startup after shutdowns, 2) freedom from adverse effects of hydraulic and waste water salinity shocks, and 3) when combined with effective flocculation and separation of solids, results in treatment of the watercraft sewage so that effluent characteristics exceed the project goals as follows:

Characteristic	Goal
Effluent Parameter	
Biochemical Oxygen Demand	< 50 ppm
Total Suspended Solids	< 50 ppm
Turbidity	< 10 JTU
Phosphates	< 1 ppm

a. Electrocoagulation Cell Geometry. The electrocoagulation cell has imposed upon it requirements which result from the intended end use. Since the cell is to contain mild steel plates which are to be consumed in the process of treating wastewater, it is imperative that flow passages in the cell assure thorough opportunity for coagulation. The assurance of maximum steel plate exposure requires that foam be removed, hydrogen gas evolved at the cathodes be vented safely, and that sludge accumulations be prevented from building up in the cell spaces.

The first shipboard electrocoagulation cell which was tested is depicted in Figure 9. The physical characteristics are tabulated in Table 3. The wastewater flow path had the influent enter at the top manifold and exit at the bottom manifold. The eight steel plates, four anodes, and four cathodes were arranged in alternating slopes. The canted plate geometry prevented collection of sludge deposits. The cell configuration proved undesirable because of air entrapment under the sloped plates and a turbulence due to hydrogen evolution and attributed to the chosen current density. The G1 configuration was operated by reducing the flowrate and the required applied current.

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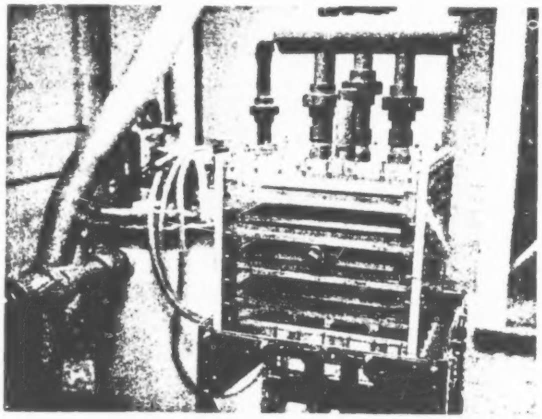

Figure 9. G1 Electrocoagulation Cell, Before Test

In view of the deficiencies of the G1 for the selected system flowrate of 5 gpm, a revision to the steel plate subassembly was made. Since the housing had been designed with an eye to test flexibility, the G2 configuration detailed in Table 3 was constructed. Figure 10 shows details of the G2 cell which included a row of flushing nozzles used for sludge dispersal into the wastewater flow. To convey the evolved gases to the vent, the influent sewage enters the cell at the lower manifold. This configuration was tested successfully and in keeping with the project guidelines, it might have been used in the prototype system with a full complement of air-flush ports. However, because the Plexiglas-G housing showed signs of crazing, a cell with the same characteristics was constructed of fibreglas and was designated G3. The G3 electrocoagulation cell is depicted in Figure 11.

TABLE 3. ELECTROCOAGULATION CELL SPECIFICATIONS

Configuration	G1	G2	G3
Housing material	Plexiglas-G	Plexiglas-G	Epoxy Fiberglas
No. of plates	8	16	16
Plate thickness	0.5 in.	0.25 in.	0.25 in.
Area of plates	21.8 ft^2	48.2 ft^2	51.3 ft^2
Volume of cell	1.92 ft^3	1.92 ft^3	1.85 ft^3
Flow volume	1.37 ft^3	1.37 ft^3	1.3 ft^3
Wt. of iron	270 lb	268 lb	271 lb
Hydraulic radius	0.45 in.	0.47 in.	0.47 in.
Reynolds No.	8780	8440	8440
Flowrate	2 gpm	5 gpm	5 gpm
Current	70 amp	175 amp	175 amp
Current density	6.4 amp/ft^2	7.2 amp/ft^2	6.8 amp/ft^2
Scrubbing jets	----	4	19
Air pressure	----	40 psig	5 psig
Nozzle diameter	----	.040 in.	0.125 in.

NOTE: Plate material in each cell was cold-rolled steel type 4130.

b Power Requirements. On board a vessel the electrocoagulation cell requires a d.c. voltage supplied to alternate plates so that the rate of ferrous ion generation can proceed in accordance with Faraday's Law. The watercraft system converts the 440 vac 3 phase to d.c. voltage and provides constant current control to the cell.

It was found that power consumption is affected by the electrocoagulation cell spacing and the conductivity of the wastewater. Since cell spacing was established at 0.5 in. because of comminuted sewage considerations, only the effect of wastewater changes in conductivity will be of consequence. The voltage required to maintain the desired 175 amp level is shown in Figure 12 for varying conductivity.

Note that for brackish wastewater, most likely the norm on the Dredge Gerig, the voltage is 5 at 95 percent efficiency in the cell power supply, the power required is 0.92 KVA.

c. Foam and Floatables Disposal. Measurements made of the solids content of the foam generated in the electrocoagulation cell revealed the desirability of diverting the foam for disposal by incineration. Because there is some hydrogen gas trapped with the foam, safe venting of the hydrogen requires that the hydrogen be released.

Several approaches were taken with the foam. The first approach was to permit passage of the foam to the rapid mix chamber of the clarifier and thereby vigorously release the entrapped gases. This approach did not work because the foam tended to buoy up the sludge blanket forming in the clarifier. A simpler tack was attempted by adding a silicone defoaming agent at 100 ppm to the Pump-Grinder. The foam was not inhibited by addition of the agent. A third alternate attempted was the conveyance of the foam from the cell directly to the sludge storage tank. However, the foam occupied significant volume intended for greater density sludge, and the foam left to its own course was extremely stable. The final refinement shown in Figure 13 was the incorporation of a sludge/foam recycle circuit utilizing a pump and ejector. By passing the contents of the tank through the ejector, dual functions are served. First the foam is separated from the entrapped gases and vented; second, the foam is withdrawn from the cell by the suction established in the ejector.

d. Safe Gas Venting. Hydrogen is evolved at the eight cathodes in the electrocoagulation cell by the electrolysis of the conductive wastewater. Since it is likely that the shipboard waste treatment system will operate in a ship compartment, it is essential that the gas be safely removed. The rate of generation of the gas for varying applied currents is shown in Figure 14. For the current level established in the prototype system, 175 amp, approximately 0.04 ft^3 min are generated.

By diluting the hydrogen in an air flow of 200 ft^3/min maintained by a Rotron, K5508, Squirrel Cage Blower, the gas mixture can be kept safely below the lower explosive limit, 4 percent, of hydrogen. Two aspects of the venting scheme need further clarification: 1) the blower outlet port has mounted to it a venturi which establishes a net suction on the hydrogen, 2) there is incorporated in the cell a sensor which inhibits power to the cell when the cell is not full of wastewater.

The venting configuration discussed was approved for certification by the U.S. Coast Guard.

e. Solids Dislodging. Because the system can be started up and shut down rapidly, there is a likelihood of solids settling of the wastewater contents in the cell. To eliminate buildup of these solids, air flushing was tested in the G2 configuration and adopted in the G3 configuration. Air flushing was selected in favor of water flushing, because the air could be conveniently vented after its scrubbing function. This was not the case with the flushing water, because this would impose an additional load on the clarifier. The air flush is planned for each hour of operation.

Polarity reversal for the purpose of alternating anodes and cathodes is planned for once a week. This will assure uniform wear of all plates.

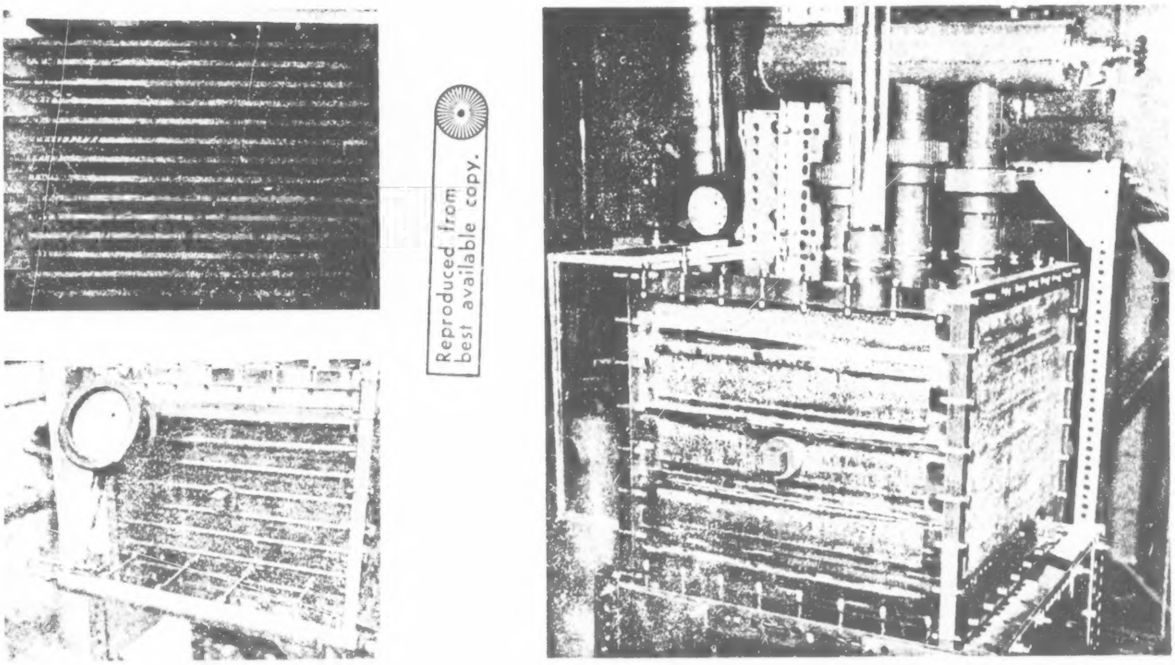

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Figure 10 G2 Electrocoagulation Cell, Internal and External Views

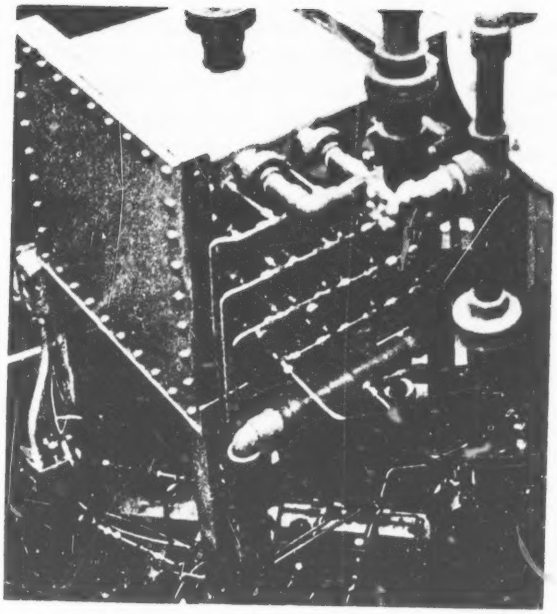

Figure 11. G3 Electrocoagulation Cell With Fibreglas Case

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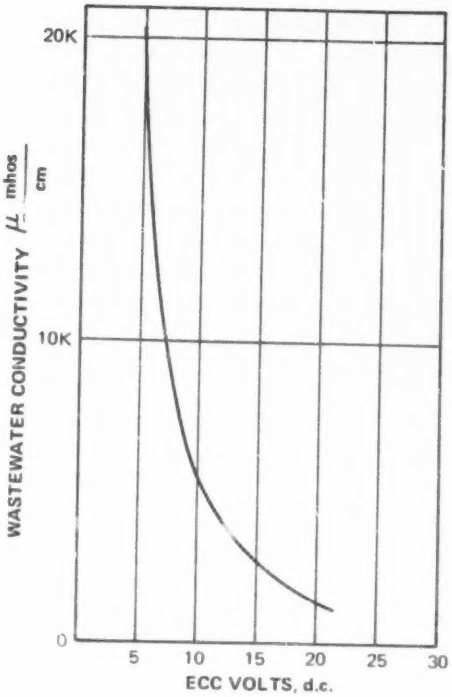


Figure 12. ECC Power vs. Wastewater Conductivity, Constant Current of 175 amp

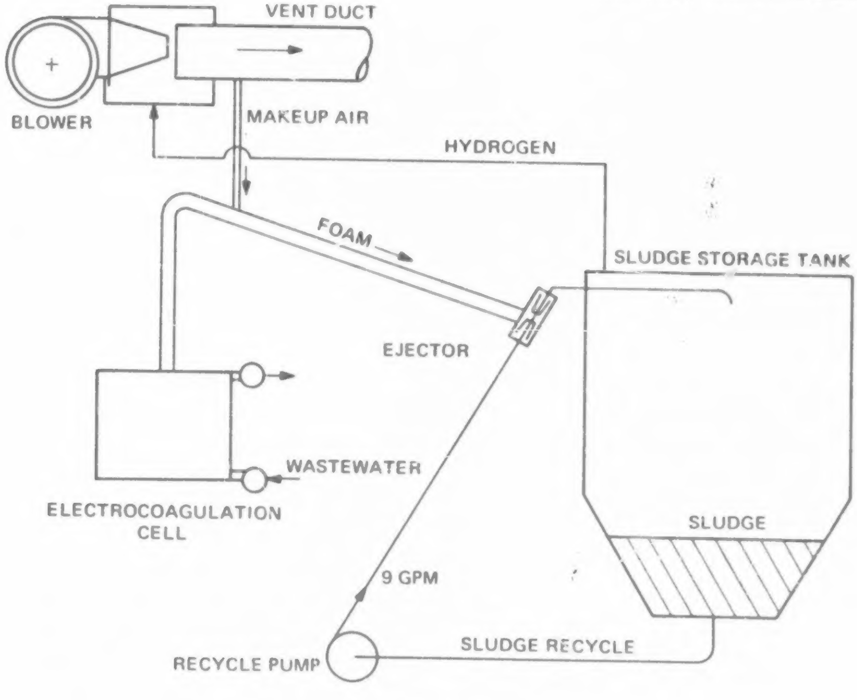

VENT DUCT
BLOWER
MAKEUP AIR
HYDROGEN
FOAM
SLUDGE STORAGE TANK
EJECTOR
WASTEWATER
ELECTROCOAGULATION CELL
SLUDGE
9 GPM
SLUDGE RECYCLE
RECYCLE PUMP

Figure 13. Foam Separation Cycle

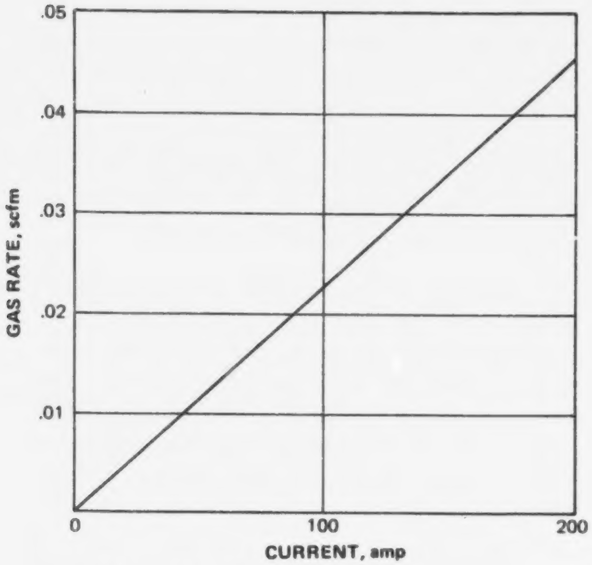


Figure 14. Hydrogen Gas Generation vs. Applied Current

ELECTROCOAGULATION CELL TEST PROGRAM

a. *Phase I Description.* Phase I tests had as an objective the determination of the critical parameters affecting electrocoagulation. The evaluation of the cell was carried out by operating with influent wastewaters of increasing complexity in composition. By approaching the study in this fashion, those waste characteristics which influence the cell operation could be studied independently. The influent materials consisted of the following tested in the order presented:

1. Tap Water + 1.25% sodium chloride (NaCl)
2. Tap Water + 2.7% NaCl
3. Tap Water + 1.25% NaCl + Magnesium Salts
4. Tap Water + 1.25% NaCl + Magnesium Salts + Calcium Salts
5. Natural Sea Water
6. Brackish Water - 50% Seawater + 50% Tap Water
7. Brackish Water + Simulated Sewage

b. *Phase I Results.* The G1 configuration electrocoagulation cell was found to have a *natural* operating pH of 9.5 to 10.5 when the influent was fresh water containing NaCl. This is very nearly an optimal range for iron flocculation with ferrous hydroxide. The pH level is maintained due to the presence of hydroxyl ions which are generated in the electrolysis of water. Maintenance of the current density in water with NaCl required low voltages. When magnesium and calcium salts are added to simulate seawater, the pH of the effluent is driven down to the 7 to 8 range. This is attributed to the formation and precipitation from solution of magnesium and calcium hydroxide. When natural seawater was treated in the cell, the pH of the effluent was driven down to 6.2 and the resultant floc was poor. Figure 15 shows the effect on effluent pH of the influents tested.

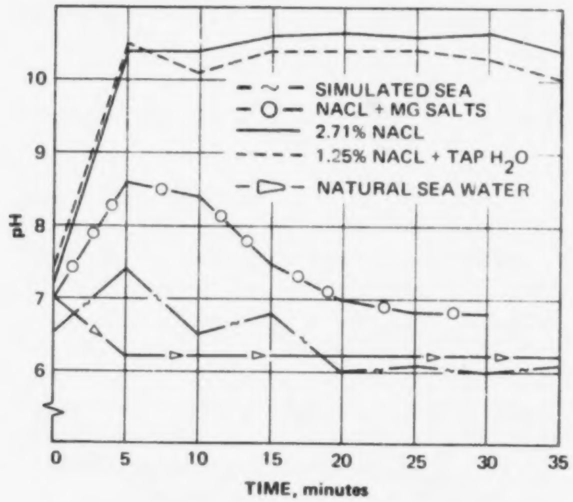


Figure 15. Effect of Dissolved Salts on Effluent pH

Recognizing that the pH would require raising, a series of tests were run utilizing simulated sewage and brackish wastewater. Brackish wastewater was made by diluting seawater with 50 percent fresh water. The current was adjusted to 35 amp/gpm flow, a value which introduced the optimal value of from 40 to 50 ppm Fe^{++}. Figure 16 presents the total iron content in the effluent as a function of applied current. The tests were run at 2 gpm to permit a reduction in current density since it was suspected that turbulence due to evolved gas in the G1 eight plate cell was disrupting coagulation.

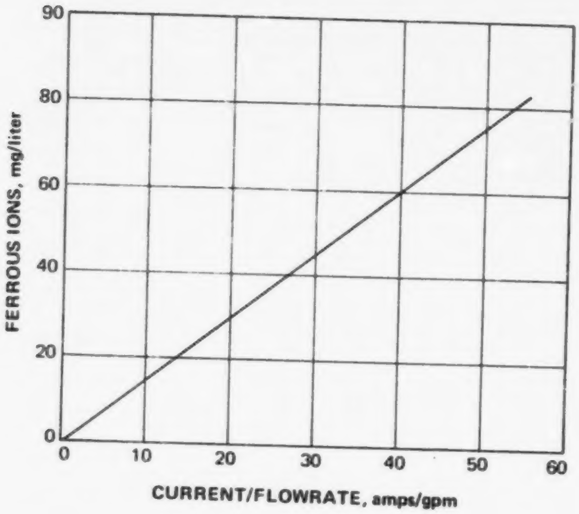


Figure 16. Fe^{++} vs. Current per Gallon per Minute

Samples of the cell effluent were withdrawn for flocculation using a flocculent aid – Percloron, a tradename by Pennwalt Chemical Co., Percloron (calcium hypo-chlorite) was evaluated because, if successful, it had the twofold advantage of raising the pH and simultaneously chlorinating the effluent. However, Percloron was not able to increase the pH at the recommended usage level because of the buffering capacity of the mixture. The pH of the effluent samples ranged from 6.6 to 7.3. Reductions in total oxygen demand (TOD) of the treated material were as high as 86 percent. However, flocculation was poor due to the low pH. In order for optimum flocculation, when the cell was processing sea water it was necessary to raise pH of the effluent by adding base (NaOH). The best flocculation occurred at pH 11. However, it was decided to operate at pH 10. Due to the buffering capacity of the sea water, it required 10 times as much base to raise the pH from 10 to 11 as it did to go from pH 6 to 10. The flocculent aid tested markedly decreased the solids settling time.

Bacterial colony counts of the unchlorinated effluent indicated a one log decrease in total viable organisms from 8×10^6 to 4×10^5. Since only insignificant amounts of residual chlorine were detected it can be assumed that the reduction in bacterial population was due to a combination of flocculation and electrolysis in the cell.

Because of an increase in average TOD measured in the last four effluent samples in Table 4, it was assumed that a homogeneous influent mixture was not being assured. The results presented in Table 5 were obtained after a stirrer was added to the influent holding tankto assure a constant composition influent for the test.

The effluent from the test tabulated in Table 5 was also titrated with sodium hydroxide in order to establish the amount of base required to reach the optimal pH range. The results are shown in Table 6.

c. *Phase I Conclusions.* The conclusions reached in test of the G1 configuration electrocoagulation cell follow:

1. The electrodes should add 40 to 50 ppm of iron to the waste for optimal flocculation. In the present configuration a current input of 35 amp/gpm is required. Efficiency of iron addition falls off due to coverage of the electrode surfaces by ferric hydroxide and precipitated sewage. The 35-amp setting has maintained the required iron levels over the evaluation period.

2. Operation in brackish or seawater requires the addition of hydroxyl irons to the effluent in order to provide suitable floc formation. The *natural* operating pH for the EC process in sea or brackish water is in the 6 – 7.5 range. This is an ideal range for aluminum flocculation. It would be advisable to study an EC cell containing aluminum electrodes for use in this environment.

3. The cell has the capability to remove 80 to 95 percent of the oxygen demanding material from the simulated sewage. This occurred whether the total oxygen demand of the influent was 500 to 2000 ppm.

TABLE 4. PHASE I TEST RESULTS – G1 CELL, BEFORE STIRRING

Sample	pH	Conductivity (μ mho/cm)	Turbidity (JTU)	Dissolved iron (ppm)	Settleable solids (ml)	TOD (ppm)	Alkalinity (ppm)	Calcium hardness (ppm)	Ortho phospate (ppm)	Residual chlorine (ppm)
Influent sewage(1)	7.8	18,500	43	1	22	420	1500	535	0.6	---
Flocculated effluent(2) (Stirring only)	6.6	19,000	20	5	24	70	---	525	0.3	---
Flocculated effluent(2) (Purifloc A-25-5 ppm)	7.0	19,000	23	3.5	---	74	---	535	0.1	---
Flocculated effluent(2) (Percloron-1.4 ppm)	7.0	19,000	17	3.5	23	64	---	520	0.1	0.1
Flocculated effluent(2) (Percloron-2.8 ppm)	7.1	19,000	17	3.5	---	64	---	530	0.1	0.1
Flocculated effluent(2) (Percloron-4.2 ppm)	7.3	19,000	17	3.5	---	60	---	535	0.1	0.1
Flocculated effluent(2) (Percloron 20 ppm)	7.2	---	25	8	---	78	---	---	0.1	---
Flocculated effluent(2) (Percloron 30 ppm)	6.6	---	26	8	22	74	---	---	---	---
Flocculated effluent(2) (Percloron 40 ppm)	6.8	---	10	8	---	78	---	---	---	---
Flocculated effluent(2) (Stirring only)	6.8	---	11	8	---	78	---	---	---	---

(1) Influent = 50 percent sea water + 50 percent tap water, synthetic feces, synthetic urine, salad oil and toilet paper. Total volume processed = 100 gal.

(2) Decanted supernatant after 2 minutes of mixing at 80 rpm, 30 minutes at 10 rpm, and 30 minutes at 0 rpm.

TABLE 5. PHASE I TEST RESULTS – G1 CELL, AFTER STIRRING

Sample	pH	Dissolved iron (ppm)	TOD (ppm)	Reduction TOD (percent)
Influent sewage(1)	8.2	---	2125	---
Flocculated effluent(2)	6.8	8	95	96
Flocculated effluent(2) (20 ppm Percloron)	7.2	8	95	96
Flocculated effluent(2) (30 ppm Percloron)	7.2	8	108	95

NOTES:

(1) Influent - 50 percent sea water + 50 percent tapwater, synthetic feces, synthetic urine, salad oil, and toilet paper.

(2) Decanted supernatant after 2 minutes stir at 80 rpm, 30 minutes stir at 10 rpm, and 30 minutes at 0 rpm.

TABLE 6. BASE TITRATION OF G1 CELL EFFLUENT

Sample	Na OH to pH 10 (ppm)	Na OH to pH 11 (ppm)
600 ml of deionized water + 30 ppm Fe	18	180
600 ml of sea water + 30 ppm Fe	300	2960
600 ml of sea water + simulated sewage	145	1450

The TOD of fresh, raw, sewage is on the order of 200 ppm. The proposed allowable maximum for effluent TOD is 50 ppm thus the cell should be able to treat raw sewage quite effectively.

4. Periodic sludge buildup in the cell probably curtails its overall operating efficiency. A sludge removal device should be incorporated as an integral part of the cell.

5. Flocculation at pH 10 (by addition of NaOH) with the addition of Purifloc A-23, (tradename of Dow Chemical product), coagulation aid (5 ppm), will be considered a standard condition. Other additives will be evaluated with respect to these conditions.

d. *Phase II Description.* The Phase I tests which utilized the G1 configuration electrocoagulation cell did establish key operating parameters for the cell. Phase II tests were run with a completely revamped internal configuration identified as the G2 cell. The requirement for a flocullent aid to accelerate flocculation and settling was identified in Phase I. Particular emphasis was placed on evaluation of the effectiveness of the flocculent aids in seawater. The evaluated candidate aids identified by their tradenames are as follows:

Purifloc C-31 (The Dow Chemcial Co.)
Purifloc C-32 (The Dow Chemical Co.)
Primafloc C-7 (Rohm and Hass Inc.)
Purifloc A-23 (The Dow Chemical Co.)
Sodium Hydroxide
Calcium Hydroxide
Sodium Aluminate (Betz Laboratories)
Nalcolyte 673 (Nalco Chemical Co.)
Nalcolyte 671 (Nalco Chemical Co.)
Separan NP10 (The Dow Chemical Co.)
Purifloc N17 (The Dow Chemical Co.)

Measurements were performed in this phase to evaluate the reduction of phosphate and ammonia nitrogen.

Use of the G2 configuration permitted testing at the proper system current density and flow rates. All test data obtained from this point on were obtained at 5 gpm and 35 amp/gpm.

e. *Phase II Results.* Initial test results of the G2 configuration cell utilizing simulated sewage and brackish waste water are shown in Table 7. The test was run with the same influent as that of the G1 tests tabulated in Table 5. Three candidate flocculent aids were selected for use in the system; Purifloc A23, Primafloc C7 and Separan NP10. The three each give floc of slightly different properties but all meet the jar test criteria of significant reduction in turbidity and suspended solids in one hour or less.

The electrocoagulation process was found to be quite effective in reduction of influent phosphate levels under the test conditions. (See Tables 8, 9, and 10.) Phosphate can be found as an insoluble precipitate in the presence of calcium and magnesium ion. The reduction should therefore be studied in fresh water environments in order to determine the effectiveness of the cell alone. A parallel test was run using chemical flocculation only. The effluents resulting from iron flocculation contained three times the total phosphate of the EC processed samples. The influent sample treated with aluminum had the same degree of phosphate reduction as the EC processed samples.

Limited evaluation of ammonia reduction was performed. The test results were variable. It was demonstrated, however, that the electrocoagulation process has the capability of ammonia removal under a given set of conditions (See Tables 8, 9, and 10). Additional lab testing is required to establish the parameters for optimal ammonia removal.

Electrocoagulation effected an 80 to 93 percent reduction in total oxygen demand (TOD) of simulated sewage. TOD reduction for raw in-house sewage ranged from 48 to 77 percent. The lowering in reduction is due to the larger amount of soluble TOD in freshly collected sanitary and culinary waste. A study was initiated in order to establish the relationship between TOD and biochemical oxygen demand (BOD). Knowledge of the influent BOD would establish whether electrocoagulation could achieve the target value of a 50 ppm maximum effluent BOD when treating fresh, watercraft type of waste material. A typical run was made with freshly collected

TABLE 7. PHASE II INITIAL TEST RESULTS – G2 CELL

Sample	Dissolved iron (ppm)	Turbidity (JTU)	TOD (ppm)	Reduction TOD (percent)	Bacterial colonies (coliform)	Bacterial colonies (total)
Influent sewage(1)	---	50	1950	---	1 x 10^4	7 x 10^5
Flocculated effluent(2) pH 10	1.2	7	154	92	0	0
Flocculated effluent(2) Purifloc 1.25 ppm pH 7	5.0	20	106	95	---	---
Flocculated effluent(2) Purifloc 2.5 ppm pH 7	3.8	16	145	93	---	---
Flocculated effluent(2) Purifloc 5.0 ppm pH 7	3.8	15	150	92	---	---
Flocculated effluent(2) Purifloc 7.5 ppm pH 7	3.8	15	169	91	0	4.3 x 10^4
Flocculated effluent(2) pH 7	---	---	---	---	4.8 x 10^3	1.5 x 10^5

NOTES:

(1) Influent = 50 percent sea water + 50 percent tap water, synthetic feces, synthetic urine, salad oil and toilet paper.

(2) Decanted supernatant after 2 minutes stir at 80 rpm, 30 minutes stir at 10 rpm, and 30 minutes at 0 rpm.

TABLE 8. G2 CELL TEST RESULTS – AMMONIA N AND PHOSPHATE REDUCTION

Sample	Flocculent (ppm)	Ammonia nitrogen (ppm)	Total phosphate (ppm)	Ortho phosphate (ppm)
Influent sewage	---	47	27.5	11.7
Flocculated effluent(1)	None	6	0.4	0.3
Flocculated effluent(1)	Adjusted to pH 10		0.5	
Flocculated effluent(1)	5 ppm A23	6	0.5	0.25
Flocculated effluent(1)	5 ppm C7		0.5	0.3
Flocculated effluent(1)	5 ppm NP 10		0.6	0.3
Flocculated effluent(1)	5 ppm Nalco 673		0.8	0.27

NOTE:

(1) Decanted supernatant after 2 minutes stir at 80 rpm, 30 minutes stir at 10 rpm, and 30 minutes at 0 rpm.

TABLE 9. G2 CELL TEST RESULTS – AMMONIA N AND PHOSPHATE REDUCTION

Sample	Flocculent (ppm)	Ammonia nitrogen (ppm)	Total phosphate (ppm)	Orthophosphate (ppm)
Influent sewage		18	12.5	4.0
Effluent	no floc aid(1)	20	0.5	0.2
Effluent	1 ppm NP10(1)	18	0.4	0.1
Effluent	2.5 ppm NP10(1)	20	0.2	0.1
Effluent	5.0 ppm NP10(1)	12	0.1	0.1
Effluent	7.5 ppm NP10(1)	12	0.2	0.1
Effluent	10.0 ppm NP10(1)	12	0.4	0.1

NOTE:

(1) Decanted supernatant after 2 minutes stir at 80 rpm, 30 minutes stir at 10 rpm, and 30 minutes at 0.

TABLE 10. G2 CELL TEST RESULTS – AMMONIA N AND PHOSPHATE REDUCTION

Sample	Flocculent	Ammonia nitrogen (ppm)	Total phosphate (ppm)	Orthophosphate (ppm)
Influent sewage		10	15.0	10
Effluent	No floc aid	10	1.2	0.4
Effluent	.08% Na-aluminate	10	.1	.1
Effluent	.16% Na-alum.	10	.1	.1
Effluent	.25% Na-alum.	10	.1	.1
Effluent	.33% Na-alum.	10	0.3	.1
Effluent	.57% Na-alum.	10	0.3	.1

sanitary waste. The data is presented in Table 11. The average effluent BOD had an absolute value of 53 ppm even though the BOD reduction was only 50 percent of the influent value. With terminal chlorination the BOD can be reduced below 50 ppm.

f. *Phase II Conclusions.* Data obtained with the 8 electrode system can be validly projected to the 16 plate system.

The data indicates that the 16 plate cell (G3) performs similarly to the 8-plate cell with respect to TOD reduction. The cell was de-sludged and cleaned with a sulfamic acid solution. The total iron generated at 35 amp/gpm was 100 ppm immediately after cleaning but decreased to 50 ppm. Further testing of the 16-plate cell will be conducted using actual raw sewage consisting of in-house culinary and sanitary waste. In view of the data from the Dredge Gerig it is also advisable to measure the ability of the system to treat watercraft waste; perferably from the Dredge Gerig. Additional bench testing will be performed in order to evaluate the TOD

TABLE 11. G2 CELL TEST RESULTS – BOD AND TOD

Sample	TOD (ppm)	BOD (ppm)	Total suspended solids (ppm)	Fixed solids (ppm)
Influent sewage	400	115	239	40.6
Effluent liquor (no floc aid)(1)	174	50	11.8	5
Effluent liquor (pH 10)(1)	160	56	21.0	5

NOTE:

(1) Decanted supernatant stirred at 80 rpm for 2 minutes, 10 rpm for 30 minutes, and 0 rpm for 30 minutes.

reduction by standard chemical flocculation methods. Limited data indicates that chemical flocculation (in one case) reduced the influent TOD by approximately 40 percent. The EC cell reduced the same influent over 90 percent.

Electrocoagulation consistently and effectively reduces influent phosphate levels. The process should be considered for application to surface waters where eutrophication is a problem.

The Electrocoagulation cell should also be studied with respect to nitrate removal.

Variable ammonia reduction was demonstrated under some test conditions. Ammonia removal is of sufficient interest to warrant further study of this application of the cell.

g. *BOD Reduction.* Further testing should be carried out to determine the correlation between TOD and BOD in vessel sewage in order to better predict watercraft performance.

h. *Phase III Description.* Previous testing and literature references had indicated that the measurement of total oxygen demand (TOD) could be used as a real time indicator of influent and effluent BOD levels. A period was reached in our test program where the electrocoagulation process had little to no effect in lowering TOD (and by inference BOD). A Phase III test plan was initiated to characterize in-house sanitary waste with respect to those parameters which affect BOD and TOD. The objective was to identify and eliminate the reason for the apparent decrease in cell efficiency and to optimize its performance for treatment of concentrated sanitary waste.

Performance of the Phase III tests and component development was completed March 6, 1970. The electrocoagulation cell was operated with sanitary waste under a variety of operating conditions: standard 35 amp/gpm, 70 amp/gpm, introduction of air into the cell while processing and preaeration of the influent for two different holding periods, Tables 12 and 13. In addition, a series of runs was made using a mixture of urea to simulate an influent containing 100 percent soluble BOD. Urea was selected since it is the major chemical constituent of urine, which was assumed to be contributing a large amount of soluble BOD to the influent.

i. *Phase III Results.* Measurements of total oxygen demand (TOD) and biochemical oxygen demand (BOD) are tabulated for the same samples in Tables 14 and 15. It can be seen from examination of these tables that the TOD may indicate an increase while the BOD decreases. The effluent BOD is either below 50 ppm or with subsequent chlorination could be lowered below 50 ppm.

The average BOD reduction was greatest when the sewage was preaerated for sixteen hours. A four hour aeration had no significant effect on the percentage BOD reduction, while adding air to the electrocoagulation cell had no beneficial effect. It was speculated that ferrous ions might be oxidized to ferric ions by the introduction of air and that a more effective flocculation and clarification would be obtained.

j. *Phase III Conclusions.* It remained to determine the minimum quantity of flocculent aid required to elevate pH and assure a clear effluent and high density sludge. This was accomplished by operating the electrocoagulation cell and clarifier. Sodium aluminate Al-46 and Separan NP10 with base are the two candidate flocculent aids.

TABLE 12. PHASE III TEST RESULTS – G2 CELL INFLUENT AERATION

Parameter		Influent(1)	Pre-aeration sample		4-hr aeration prior to treatment		
			Effluent(2)	Effluent(2) (pH 10)	Influent(1)	Effluent(2)	Effluent(2) (pH 10)
Urea N	(ppm)	52	52	---	---	60	64
Ammonia N	(ppm)	20	15	16	20	20	17
TSS	(ppm)	390	20	20	368	20	20
FSS	(ppm)	206	20	20	200	20	20
TOD	(ppm)	---	95	---	---	---	---
BOD	(ppm)	110	39	32	90	31	38
pH		7.2	7.4	10.0	7.5	7.4	10.0
Turbidity	(JTU)	19	19	18	29	37	9
Residual Fe	(ppm)	---	---	---	---	---	---
Total Fe	(ppm)	---	120	---	---	31	---

NOTES:

(1) Influent = 50% sea water + 50% sanitary sewage and wastewater from RESD, Research and Engineering Center.

(2) Decanted supernatant flocculated with 2 ppm NP10 and stirred at 80 rpm for 2 minutes, 10 rpm for 30 minutes, and 0 rpm for 30 minutes.

UPFLOW CLARIFIER

a. *Description.* To make the electrocoagulation process effective in a waste treatment system, flocculation and settling must occur rapidly. In laboratory tests this clarification may be accomplished by jar-test settling or centrifugation, both of which require decanting the clarified liquor so as to complete separation. Achieving the same degree of clarification in a constant flow system, which may be in a state of motion and where severe limitations exist on detention time of wastewater flow, dictates the need for planning a significant development effort.

An evaluation of techniques and hardware available for solids separation in a continuous flow process resulted in the conclusion that an independent development would be required. A review of the hardware used for settling in land-based applications revealed that a truck mountable Upflow Clarifier could be redesigned to operate while in motion. The typical motion specifications commonly accepted are shown in Figure 17.

Not unlike the open-topped experimental electrocoagulation cells, the design of the open-topped clarifier required extensive change to make it suitable for use in a watercraft. The clarifier was sized to provide a one hour

TABLE 13. PHASE III TEST RESULTS – G2 CELL INFLUENT AERATION

Parameter		Pre aeration sample		16 Hr aeration prior to treatment		
		Influent(1)	Effluent(2) (35 amp/gpm)	Influent(1)	Effluent(2) (35 amp/gpm)	Effluent(2) (35 amp/gpm) pH 10
Urea N	(ppm)	32	30	30	26	34
Ammonia N	(ppm)	10	10	8	9	9
TSS	(ppm)	460	108	298	20	20
FSS	(ppm)	62	20	216	20	20
TOD	(ppm)	---	---	---	---	120
BOD	(ppm)	82	35	136	13	17
pH		7.5	7.8	7.1	6.6	10.0
Turbidity	(JTU)	59	21	44	100	4
Residual Fe	(ppm)	0	0	---	---	---
Total Fe	(ppm)	---	---	0	64	---

(1)Influent = 50% sea water + 50% sanitary sewage and wastewater from RESD, Research and Engineering Center.

(2)Decanted supernatant flocculated with 2 ppm NP10 and stirred at 80 rpm for 2 minutes, 10 rpm for 30 minutes, and 0 rpm for 30 minutes.

TABLE 14. PHASE III TEST RESULTS – G2 CELL CURRENT DENSITY EFFECTS

Parameter		Normal run		Cleaned cell				Air Added to ECC during run(1)		
		Influent(2)	Effluent(3) (35 amp/gpm)	Influent(2)	Effluent(3) (35 amp/gpm)	Influent(2)	Effluent(3) (70 amp/gpm)	Influent(2)	Effluent(3) (15 amp/gpm)	Effluent(3) (70 amp/gpm)
Urea N	(ppm)	25	25	---	---	---	---	46	40	40
Ammonia N	(ppm)	20	20	25	20	23	12	23	22	22
TSS	(ppm)	128	20	24	20	20	20	322	<20	<20
FSS	(ppm)	28	20	20	20	20	20	38	<20	<20
TOD	(ppm)	450	218	420	278	390	526	---	---	---
BOD	(ppm)	186	60	206	63	174	63	88	58	60
pH		7.3	7.1	7.6	8.3	7.6	8.0	7.5	7.5	7.6
Turbidity	(JTU)	63	10	70	23	62	20	48	24	28
Residual iron	(ppm)	65	1.2	---	---	---	---	---	---	---

(1)Air added at 10 scfm

(2)Influent = 50% sea water + 50% sanitary sewage and wastewater from RESD, Research and Engineering Center

(3)Decanted supernatant flocculated with 2 ppm NP10 and stirred at 80 rpm for 2 minutes, 10 rpm for 30 minutes, and 0 rpm for 30 minutes

TABLE 15. PHASE III TEST RESULTS – G2 CELL UREA INFLUENT

Parameter		Influent[1]	15 amp/gpm		35 amp/gpm		70 amp/gpm	
			Effluent[2]	Effluent[2] (pH 10)	Effluent[2]	Effluent[2] (pH 10)	Effluent[2]	Effluent[2] (pH 10)
Urea N	(ppm)	100	90	---	100	---	46	--
Ammonia N	(ppm)	7	17	15	14	12	9	---
TSS	(ppm)	20	20	20	20	20	20	20
FSS	(ppm)	20	20	20	20	20	20	20
TOD	(ppm)	240	195	190	250	250	260	235
BOD[3]	(ppm)							
pH		7.2	6.4	10	6.8	10	8.0	10
Turbidity	(JTU)	20	43	14	24	7	32	6
Residual iron	(ppm)	---	---	---	---	---	---	---
Total Iron	(ppm)	---	38	---	119	---	264	---

[1] Influent = 50% sea water + 50% tap water and 76 grams urea.

[2] Decanted supernatant stirred at 80 rpm for 2 minutes, 10 rpm for 30 minutes, and 0 rpm for 30 minutes.

[3] No 0_2 demand exerted by urea in the BOD determination.

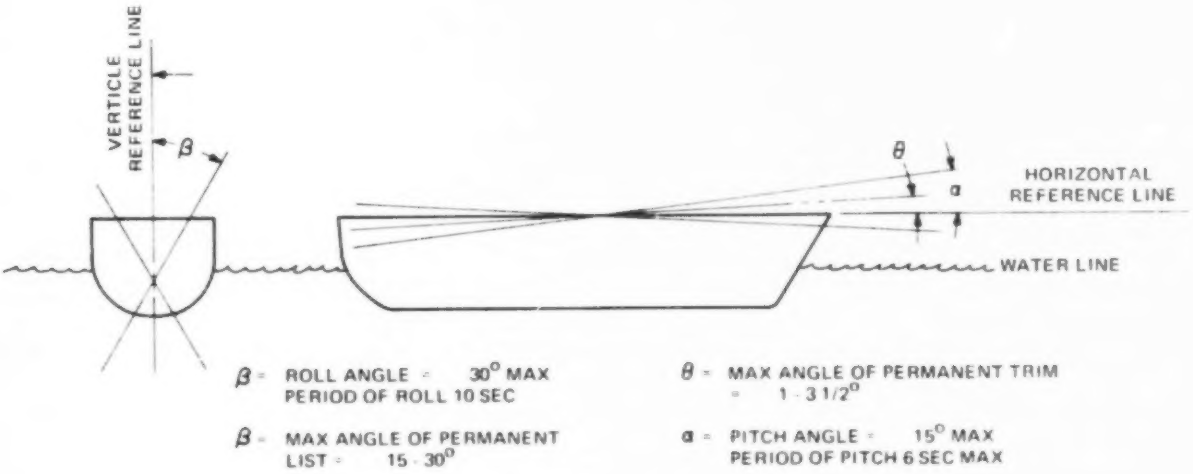

VERTICLE REFERENCE LINE
β
θ
α
HORIZONTAL REFERENCE LINE
WATER LINE
β = ROLL ANGLE = 30° MAX
PERIOD OF ROLL 10 SEC
β = MAX ANGLE OF PERMANENT
LIST = 15 - 30°
θ = MAX ANGLE OF PERMANENT TRIM
= 1 - 3 1/2°
α = PITCH ANGLE = 15° MAX
PERIOD OF PITCH 6 SEC MAX

Figure 17. Motions Comprising Shipboard Environments

detention, a design objective which while keeping the component volume down dictates that a flocculent aid be used to speed sedimentation by gravity.

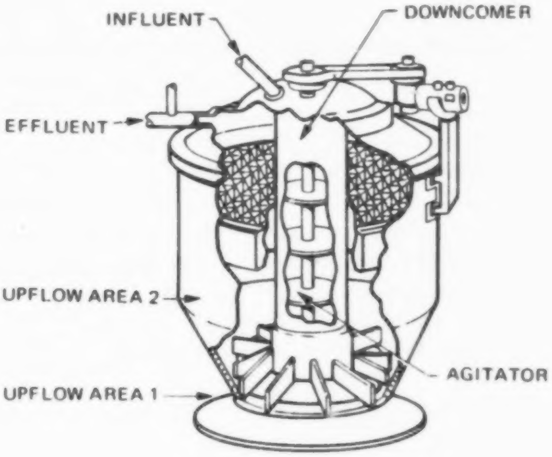
After the decision was made to use an upflow clarifier for solids separation, it was necessary to investigate usage of a model because of the expense of a full-sized unit. Mathematical study (Reference 3) of the correlations between a model and the full scale component concluded the following:

1. If the ½-scale geometric model and full scale component are operated with the actual detention time, then the effluent from the model is not representative because of a shorter settlement height.

2. If the scaled model and full scale component are operated with the actual overflow rate, then the effluent from the model is degraded since detention time would be less for the model effluent.

Based on the undesirable compromises indicated for modeling, a full size clarifier fabrication was subcontracted. The analysis of sedimentation in dynamic environments (Reference 3) had also concluded that a restrained body of liquid could be considered to behave as a rigid mass. The existent model clarifier made by Met Pro Water Treatment Corporation with the changes made by GE-RESD to eliminate sloshing is depicted in Figure 18.

The upflow clarifier configuration which is incorporated in the shipboard system evolved in three stages of development. Each of the hardware modifications was made to further increase the total suspended solids content of the withdrawn sludge. An objective established by the incinerator capacity was a sludge containing 2 percent total suspended solids (TSS). For a system which treats 2500 gal/day of wastewater with an average of 720 ppm TSS, a 1 percent TSS sludge requires incineration of approximately 200 gal of sludge, while a 2 percent sludge requires approximately 100 gal. The additional percentage reduces the incinerator load in half.



$$\frac{A_2}{A_1} = \frac{11.47\ \text{ft}^2}{0.59\ \text{ft}^2} = 19.5$$

$$\frac{V_1}{V_2} = \frac{.113\ \text{ft/mm}}{.058\ \text{ft/min}} = 19.5$$

Figure 18. Upflow Clarifier Cutaway View

A sludge withdrawal schedule of four withdrawals lasting three minutes at 2 gpm/hr of elapsed operation will be initially programmed. Indications that long term operation of the clarifier makes achievement of a 2 percent TSS sludge possible will permit adjustment of this schedule in Phase II tests.

The development of the clarifier concluded with a successful test on the motion simulation platform.

b. *Development Effort.* An extensive development effort was expended on the upflow clarifier. This may be in part explained by the need to develop an effective sedimentation tank operating in the short time of one hour and also assure similar performance while in motion. The primary test objective was a continuing improvement in the total suspended solids content of the sludge. The work in sludge concentration continues in the laboratory even with shipment of the prototype.

In the early period of testing, difficulties were encountered in getting sufficiently long runs because of inadequate influent sewage. Changes to the building sewage line made during the test program eliminated the sewage shortage.

In the following discussions regarding the hardware configuration tested, the performance results will be examined and the rationale for any changes developed. The three configurations are distinguished as were the cells by group callouts: G1, G2 and G3.

The G1 clarifier configuration will be described in some detail since it comprises the heart of all three configurations. The internal configuration is depicted in Figure 19 and the external configuration in Figure 20. The capacity of the unit is 300 gal which at a wastewater flow of 5 gpm provides a detention time of one hour.

The wastewater influent contents of floc and flocculent aid enter near the center of the clarifier into a volume containing a rotating shaft and disks. This volume is referred to as a downcomer and it is sized to provide approximately 20 min of mixing. At the base of the downcomer the rotational velocity of the flow is reversed and the upflow begun in a gradually increasing volume. Here the process of sedimentation builds up a sludge blanket. Supernatant upflows over the weir level and is then disinfected in the chlorination tank. The sludge is withdrawn when the blanket level interrupts the light source and photoelectric eye.

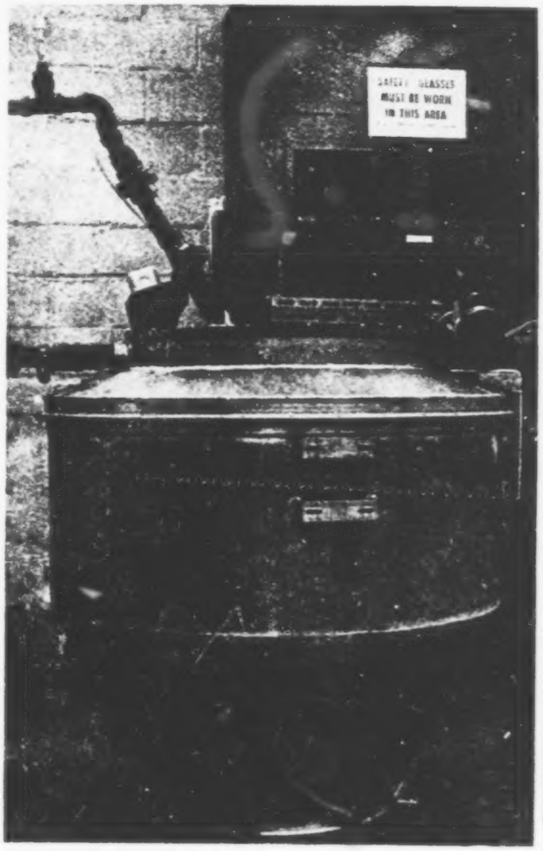


Figure 19. G1 Upflow Clarifier Photograph

Reproduced from best available copy.

The G2 clarifier configuration shown in Figure 20 adds to the basic configuration a 50-gal concentrator tank which is connected to the clarifier. Sludge is transferred through the connecting pipe at 0.5 gpm. Clarified liquid from each tank in the ratio of 4.5 to 0.5 gpm results. The photoelectric eye detection scheme for sludge withdrawal was replaced by sequenced withdrawals.

The G3 clarifier configuration shown in Figure 21 evolved during system test. This change altered the mode of operation of the clarifier and concentrator as follows: sludge was transferred by pump to the concentrator and the concentrator effluent was recycled to the downcomer.

c. *G1 Clarifier Test Program.* The test program to evaluate the solids separation capability of the G1 clarifier began with influents of known solids composition. Initial tests utilized the electrocoagulation cell effluent, comprised of seawater and ferrous hydroxide, to evaluate sedimentation characteristics.

Elemental tests to study sludge blanket detection techniques and sludge withdrawal rates were performed on this clarifier. An objective for total suspended solids content of 2 percent in the withdrawn sludge was established on the basis of incinerator capacity. The proposed purchased incinerator had a stated capacity of 100 gallons daily, which yields the required total suspended solids content as follows:

The average total suspended solids influent to the clarifier is from Table 16, 720 ppm, and including 115 ppm of $Fe(OH)_2$ is therefore .... 835 ppm TSS
allowable effluent level . . . . 50 ppm TSS
the daily wastewater flow is . . . . 2500 gal
and, the solids to be removed daily . . . .

$$\frac{2500 \text{ x } (835\text{-}50) \text{ x } 3.79}{454 \text{ x } 10^3} = 16.2 \text{ lb}$$

which results in a concentration requirement of:

16.2 lb TSS per 100 gal or

19,400 mg/l ≈ 2 percent

The performance of the G1 Clarifier is tabulated in Table 17. The grab samples taken during the sludge withdrawals at the times noted had a total suspended solids content generally less than 1 percent. The double entries under run 2 indicates different sample times.

Several attempts to utilize a light source and photoelectric eye to sense sludge blanket height failed. Because of discoloration to the sight windows by sludge, the optical system proved unreliable.

Sludge withdrawal was improved by operating the agitator continuously for breakthrough of supernatant liquor was found if the pump-out occurred without rotation of the blanket.

The initial tests of the clarifier indicated that with addition of a flocculent aid, separation, compaction, and clarification were occurring in the detention time of one hour. The clarified effluent sampled showed excellent total suspended solids reduction in influent levels. However, the total suspended solids content of the sludge averaged less than 1 percent or 10,000 ppm.

Based on these test results showing that insufficient compaction of the sludge blanket occurs in sixty minutes, the clarifier was returned for a major alteration to add a 50-gal concentrator tank. By transferring sludge from the clarifier at 0.5 gpm, an additional 100 min of compaction would be provided.

d. *G2 Clarifier Test Program.* This configuration clarifier which added the concentrator was extensively tested with the full range of wastewater influents. Within this configuration several operating modes were

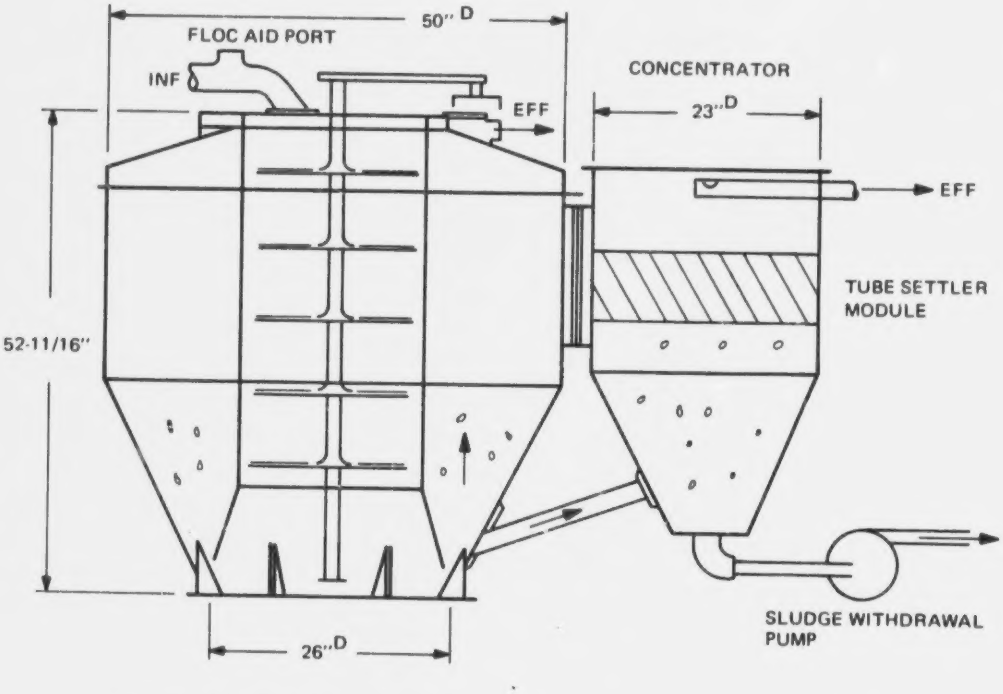


Figure 20. G2 Upflow Clarifier with Concentrator, Elevation View

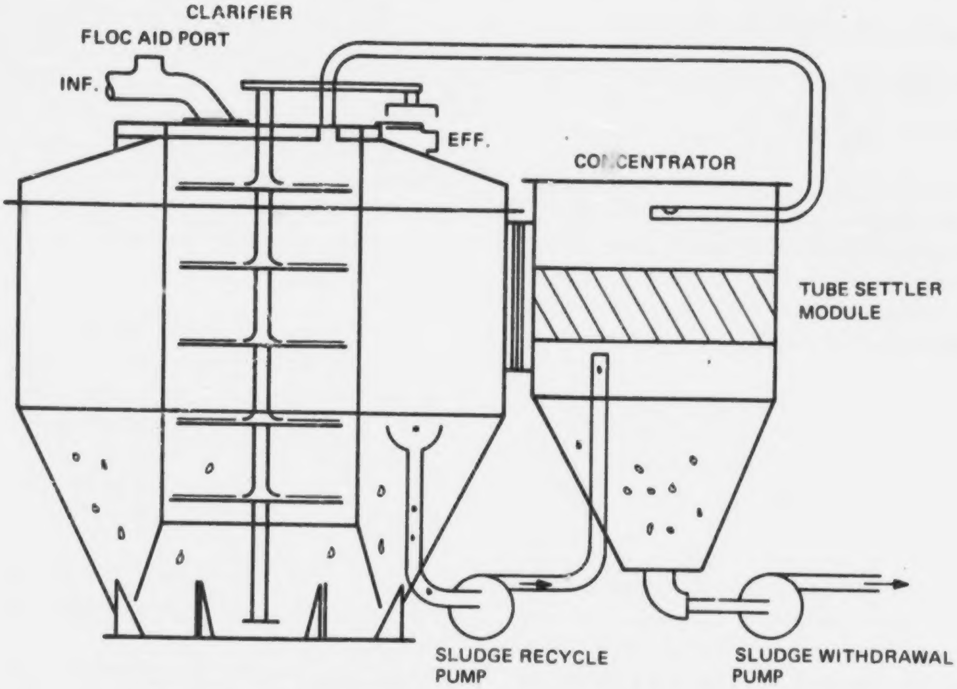


Figure 21. G3 Upflow Clarifier Modified After System Test

TABLE 16. RESULTS OF THE WASTEWATER SURVEY DREDGE GERIG

	Flow (gpm)	Biochem. 0_2 demand (ppm)	Total O_2 demand (ppm)	Conductivity[1]	Ortho phosphate (ppm)	Total phosphate (ppm)	Total suspended solids (ppm)	Total volatile solids (ppm)	Detergent (ppm)	Ca++ (ppm)	Mg++ (ppm)	pH
High	4.8	879	2308	38	35	123	1033	863	210	124	269	8.4
Low	0.8	402	612	16	18	32	556	213	6	33	55	6.7
Avg	2.2	665	1229	28	25	64	720	532	64	88	163	8.0
High	4.0	836	825	28	29	126	1390	1170	906	198	400	8.5
Low	0.5	185	175	9	12	12	121	89	5	75	112	6.9
Avg	2.0	554	483	16	21	50	509	443	174	125	256	7.9
High	2.6	790	1275	23	25	42	654	532	102	151	272	7.7
Low	1.7	590	700	9	13	32	280	240	25	90	147	7.1
Avg	2.2	713	950	18	21	37	464	382	63	116	214	7.5

(1)Conductivity (μ mhos/cm x 10^{-3})

investigated: These include reduction in the speed of rotation of the agitator, pump rate and duration of withdrawal of sludge, and the effect on sludge of intermittent and continuous transfer. Some effort was devoted to evaluation of an automatic decant of supernatant from the concentrator prior to sludge withdrawal.

Only the two conditions pertaining to sludge transfer will be further discussed. Intermittent sludge transfer is defined as transfer at 0.5 gpm whenever the system is operating. Continuous transfer is defined as 0.5 gpm flow, which is continuously recycled into the downcomer even when the system is not operating. If sludge transfer is continuous, then the clarifier-sludge requirements is derived from Figure 22.

Let:

C = total suspended solids concentration, ppm

W = flow, gpm

t = time, min

Then:

$$C_4 = \frac{(C_1 - C_2) \times W_1 \times t_a - C_3 W_3 t_c}{W_4 t_b + (W_4 + W_5) t_d}$$

t_a = 500 min of system operation

t_b = 1392 min excluding sludge withdrawal time

t_c = 1440 min

t_d = 48 min of sludge withdrawal

W_1 = 5 gpm

W_3 = 0.5 gpm

W_4 = 0.5 gpm

W_5 = 2.0 gpm

Also, the minimum clarifier sludge concentration follows

$$C_4 = \frac{(835 - 50) \times 5 \times 500 - 50 \times 0.5 \times 1440}{0.5 \times 1392 + (0.5 + 2.0)\, 48}$$

$$C_4 = 2361 \text{ ppm}$$

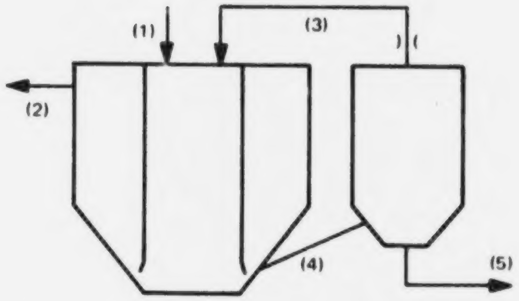


Figure 22. Clarifier-Sludge Derivation Figure

This level is achievable in the clarifier as demonstrated in test. A similar computation for a concentrator operating on intermittent sludge transfer yields a requirement for C_4 = 10,000 ppm. Without a major change such as in detention time or volume, an intermittent transfer is not practical.

The performance of the G2 clarifier, during runs 2 through 10, is tabulated in Table 18 with definition of the test conditions established. Based on further tests of the optical sensing system for sludge blanket detection, the positive sensing mode was replaced by preprogramming sludge withdrawals based on system operating time.

The most favorable sludge total suspended solids content was achieved by the shorter duration, higher pump rate withdrawal as demonstrated in run 10. The effluent TSS content was generally below 20 ppm.

TABLE 17. G1 CLARIFIER TEST RESULTS, RUNS 1 AND 2

	Test Run		
	1	2	
Clarifier flow rate	5 gpm	5 gpm	
Flocculent aid rate	3 ppm NP10	4 ppm NP10	
Test duration	80 min	140 min	
Agitator speed	115 rpm	115 rpm	
Influent	Seawater	Seawater	
Sample times	78 min	80 min	100 min
Clarifier influent	115 ppm	115 ppm	—
Clarifier effluent	<20 ppm	—	—
Clarifier sludge TSS	3038 ppm	9159 ppm	9680 ppm

TABLE 18. G2 CLARIFIER TEST RESULTS, RUNS 3 THROUGH 10

Run	3	4	5	6	7	8	9	10
Clarifier flowrate (gpm)	5	5	5	5	5	5	5	5
Flocculent aid rate (ppm)	2.5 NP10	2.5 NP10	.05 % sodium aluminate	2.5 A23 + NaOH	0.1% sodium aluminate	.05 % sodium aluminate	.05 % sodium aluminate	2.5 NP10
Test duration (min)	260	90	195	140	165	140	165	117
Agitator speed (rpm)	115	54	54	54	54	54	54	54
Influent	Seawater	Seawater + sewage	Seawater + sewage	Seawater + sewage	Seawater + sewage	Seawater + sewage	Seawater + sewage	Seawater + sewage
Sample times (min)	60 260	10 35 70 90	75 135 195	140	15 135 155 165	60 120 130 140	65 140 155 165	88 92 95 107 117 140 144 145.5 147
Clarifier influent TSS (ppm)	238	1260 946 648 782	788 -- --	358	562 -- -- --	304 -- -- --	380 -- -- --	746 -- -- -- -- -- -- -- --
Clarifier effluent TSS (ppm)	--	<10 54 <10 <100	<20	<20	<20 -- -- --	<20 -- -- --	<20 -- -- --	<20 -- -- -- -- <20 -- -- --
Clarifier sludge TSS (ppm)	--	642 1754 2020 2660	-- 2990 3060	--	-- -- 1708 --	-- -- 1288 --	-- 2198 --	2184 2196 1776 1936 6552 2256 1928
Concentrator sludge TSS (ppm)	7702 13300	2400 9140 13260 13624	3950 4290 4560	6996 Composite	6972 370 122 5/8 gpm*	4134 240 88 5/8 gpm*	10052 3816 258 5/8 gpm*	14932 5008 2852 2436 0.75 gpm* 8268 10074 8730 2 gpm*
Concentrator flowrate (gpm)	0.25	0.33	0.5	0.5 Decanted Conc.	0.5 Decanted Conc.	0.5 Decanted Conc.	0.5 Decanted Conc.	0.75

NOTE: *These samples were obtained during continuous sludge withdrawal

TABLE 19. G3 CLARIFIER TEST RESULTS, RUNS 11 THROUGH 16

Run	11			12		13					14		15			16	
Clarifier flowrate (gpm)	5			5		5					5		5			5	
Flocculent aid rate (ppm)	.05 % sodium aluminate			.05 % sodium aluminate		0.1 % sodium aluminate					0.1% sodium aluminate		0.1% sodium aluminate			0.1 % sodium aluminate	
Test duration (min)	120			120		270					180		216			132	
Agitator speed (rpm)	54			54		120					150		150			150	
Sample time (min)	60	90	120	60	120	60	120	180	240	270	60	180	60	174	216	60	132
Clarifier influent TSS (ppm)	836	--	680	828	552	1000	824	716	400	484	872	672	856	436		752	356
Clarifier influent BOD (ppm)				396			408	390									
Clarifier effluent TSS (ppm)	26	--	<20	50	34	34		22	40		68	58	108	58		52	28
Clarifier effluent BOD (ppm)				--	99			145	113								
Concentrator sludge TSS (ppm)	12492	9348	11868						12470	11870	26358		20594			19987	
Clarifier influent Turb (JTU)						90		130	100	90	125	125	130	70		110	115
Clarifier effluent Turb (JTU)						24		16	18	24	28	28	30	17		30	24

The flocculent aids established as promising in jar tests – NPIO + NaOH and sodium aluminate – both aided suitable sludge blanket formation within the hour detention time.

The decant technique tried in runs 6 to 9 did not improve the solids content of the sludge sufficiently to warrant the complexity of an additional electrically controlled valve.

In conclusion the clarifier configuration of run 10 was considered the best performer of the test sequence. Consequently, it was incorporated for the start of system test. The sludge withdrawal rate was established at 2 gpm, and the recycle and transfer was established at 0.75 gpm.

The flocculent aid selected was NPIO with added base, NaOH.

e. *G3 Clarifier Test Program.* The changes incorporated to make the G3 configuration were not extensive. However, they are the result of insights gained during longer term tests with the increased sanitary sewage source.

Evolvements during test are best understood by reference to Figure 21 which schematically indicates the G3 configuration. Relocation of the sludge withdrawal port in the clarifier transfers higher density sludge from the blanket to the upper third of the concentrator. The result appears to be a higher concentration in the sludge because of a higher initial concentration. A corollary change was the increase of the transfer rate to 4 gal/min, the net result being greater solids content within the concentrator.

The performance of the G3 clarifier is tabulated in Table 19. The flocculent aid selected for use on the ship was sodium aluminate because of the superior turbidity reduction which results. Clarifier effluent continued to yield effluents with a total suspended content of less than 20 ppm. The biochemical oxygen demand was reduced by 75 percent on the average. The reduction to below 50 ppm can be achieved by final chlorination of the effluent. Sufficient data exists to assure that the effluent BOD can be reduced to 50 ppm from the unchlorinated effluent levels.

In conclusion the flocculent aid rate and chlorination rate remain to be determined in the initial trial runs on the watercraft utilizing vessel waste.

f. *G3 Clarifier Motion Simulation Test.* This test subjected the G3 configuration clarifier to a motion test on the specially designed apparatus depicted in Figure 23. The test performed at a rate of ± 20 degrees in 10 sec demonstrated the nonsloshing design features of the clarifier.

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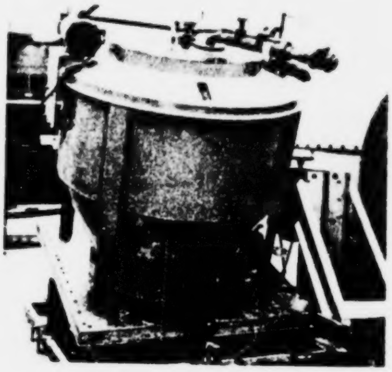
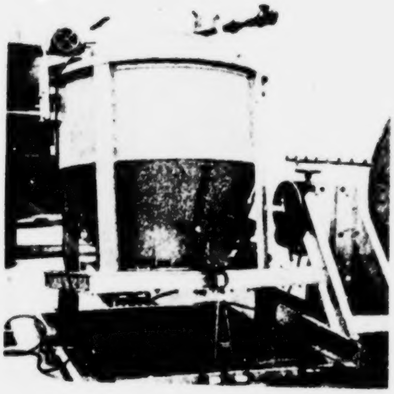


AT -20 DEG



AT +20 DEG

Figure 23. Motion Simulation On G3 Clarifier

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ACKNOWLEDGEMENT

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APPENDIX B

SUMMARY OF GERIG SWTS TEST DATA

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	Suspended Solids ppm	Coliform MPN col./100ml
TAMPA, FLORIDA							
10-27-70	System Effluent	1145	9.4	-	65	40	-
	System Effluent	1400	6.9	-	90	50	-
10-28-70	System Influent	0800	7.6	-	140	880	-
	System Influent	0900	9.2	-	150	100	-
	System Influent	1115	7.6	-	720	940	-
	System Effluent	-	9.8	-	55	80	-
	System Effluent	0900	9.7	-	70	25	-
	System Effluent	1115	9.6	-	155	25	-
10-29-70	System Influent	0700	7.6	-	110	950	-
	System Influent	1000	7.9	-	150	940	-
	System Influent	-	8.1	-	145	320	-
	System Influent	-	7.6	-	270	-	-
	System Effluent	0700	9.6	-	50	20	-
	System Effluent	1000	9.5	-	70	80	-
	System Effluent	-	9.5	-	60	70	-
	System Effluent	-	9.5	-	80	70	-
PASCAGOULA, MISSISSIPPI Mean Data							
1-8-71	System Influent	-	-	-	140	420	-
	System Effluent	-	-	-	15	20	-
1-9-71	System Influent	-	-	-	190	150	-
	System Effluent	-	-	-	20	20	-
1-10-71	System Influent	-	-	-	270	430	-
	System Effluent	-	-	-	75	5	-
1-11-71	System Influent	-	-	-	150	1340	-
	System Effluent	-	-	-	40	10	-

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Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	Suspended Solids ppm	Coliform MPN col./100ml
BRUNSWICK, GEORGIA							
3-11-71	System Influent	-	-	-	575	690	-
	System Effluent	-	-	-	220	54	-
3-13-71	System Influent	-	-	-	1530	1450	-
	System Influent	-	-	-	660	290	-
	System Influent	-	-	-	400	160	-
	System Influent	-	-	-	1400	630	-
	System Effluent	-	-	-	210	17	-
	System Effluent	-	-	-	470	50	-
	System Effluent	-	-	-	300	30	-
	System Effluent	-	-	-	280	95	-
3-14-71	System Influent	0850	5.7	-	530	520	$>1 \times 10^6$
	System Influent	1030	6.1	-	580	780	$>1 \times 10^6$
	System Influent	1230	7.5	-	130	210	$>1 \times 10^6$
	System Influent	1430	8.2	-	270	470	$>1 \times 10^6$
	System Effluent	0850	8.3	< 0.1	190	60	$>1 \times 10^3$
	System Effluent	1030	8.4	< 0.1	170	60	25
	System Effluent	1230	8.4	< 0.1	190	80	1
	System Effluent	1430	8.4	< 0.1	190	80	$>1 \times 10^3$
3-15-71	System Influent	0900	7.8	-	1980	800	$>1 \times 10^6$
	System Influent	1100	6.8	-	1350	640	$>1 \times 10^6$
	System Influent	1225	6.4	-	762	410	$>1 \times 10^6$
	System Effluent	0900	8.6	< 0.1	180	15	$>1 \times 10^3$
	System Effluent	1100	8.6	< 0.1	240	20	$>1 \times 10^3$
	System Effluent	1225	8.6	< 0.1	200	25	$>1 \times 10^3$
3-16-71	System Influent	0700	7.2	-	360	720	-
	System Influent	1400	6.9	-	900	650	-

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	Suspended Solids ppm	Coliform MPN col./100ml
BRUNSWICK, GEORGIA							
3-17-71	System Influent	0920	6.5	-	250	520	-
	System Influent	1130	7.6	-	400	410	-
	System Influent	1345	8.3	-	440	250	-
	System Influent	1445	7.7	-	190	360	-
	System Effluent	0920	7.7	40	160	90	< 1.0
	System Effluent	1130	8.2	15	195	60	< 1.0
	System Effluent	1345	7.2	15	260	100	< 1.0
	System Effluent	1445	7.1	20	270	65	< 1.0
	Backage Water	-	7.8	-	2	-	1.7×10^4
3-19-71	System Influent	1255	6.5	-	450	300	-
	System Influent	1400	7.0	-	500	320	-
	System Influent	1445	7.7	-	420	460	-
	System Effluent	1155	8.4	17	350	65	< 1.0
	System Effluent	1255	8.3	18	320	60	< 1.0
	System Effluent	1400	7.5	36	450	70	< 1.0
	System Effluent	1445	7.5	44	410	70	< 1.0
3-20-71	System Influent	0800	7.3	-	930	580	-
	System Influent	0945	8.6	-	940	910	-
	System Influent	1230	7.2	-	860	350	-
	System Influent	1430	6.7	42	490	370	-
	System Effluent	0715	7.3	225	240	70	< 1.0
	System Effluent	0945	8.4	20	250	60	$> 1 \times 10^3$
	System Effluent	1230	8.4	13	310	50	< 1.0
	System Effluent	1420	8.4	11	290	60	< 1.0
3-21-71	System Influent	0725	6.8	-	650	400	-
	System Influent	0930	7.2	-	530	710	-
	System Influent	1130	8.8	-	610	630	-
	System Influent	1330	7.2	-	1130	630	-

Location/Date	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	Suspended Solids ppm	Coliform MPN col./100ml
3-21-71	System Effluent	0725	9.0	15	145	40	< 1.0
	System Effluent	0930	8.9	27	190	50	< 1.0
	System Effluent	1130	8.7	21	230	45	< 1.0
	System Effluent	1330	8.5	11	170	50	< 1.0
3-22-71	System Influent	0725	7.3	-	460	370	-
	System Influent	0935	9.5	-	-	1510	-
	System Influent	1210	8.0	-	550	210	-
	System Influent	1430	7.8	-	670	190	-
	System Effluent	0725	8.9	11	285	40	< 1.0
	System Effluent	0940	8.9	32	225	30	< 1.0
	System Effluent	1210	8.8	33	300	50	< 1.0
	System Effluent	1430	8.4	14	320	60	< 1.0
3-23-71	System Influent	0845	7.0	-	1400	720	-
	System Influent	1100	8.7	-	330	410	-
	System Influent	1230	7.6	-	620	420	-
	System Influent	1415	8.1	-	320	430	-
	System Effluent	0850	7.7	55	180	50	< 1.0
	System Effluent	1100	7.7	69	245	80	< 1.0
	System Effluent	1230	8.4	138	225	60	< 1.0
	System Effluent	1500	8.5	127	300	170	< 1.0
3-24-71	System Influent	0930	6.2	-	Depleted	1600	-
	System Influent	1115	5.2	-	430	360	-
	System Influent	1300	7.3	-	660	400	-
	System Influent	1430	8.8	-	380	480	-
	System Effluent	0930	7.8	84	205	350	< 1.0
	System Effluent	1115	9.1	80	190	55	< 1.0
	System Effluent	1300	8.9	61	245	40	< 1.0
	System Effluent	1430	8.8	49	210	50	< 1.0

Location/Date	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	Suspended Solids ppm	Coliform MPN col./100ml
3-25-71	System Influent	1045	7.2	-	220	500	-
	System Influent	1230	7.6	-	100	180	-
	System Influent	1445	7.4	-	130	280	-
	System Effluent	1045	8.3	27	180	55	$>1 \times 10^3$
	System Effluent	1230	8.7	-	125	46	<1.0
	System Effluent	1315	8.9	50	110	140	<1.0
	System Effluent	1500	8.8	27	95	36	18
	Background Water	-	7.8	-	1	-	5×10^4
3-26-71	System Influent	0845	7.1	-	370	620	-
	System Influent	1040	7.2	-	820	810	-
	System Influent	1230	7.3	-	610	420	-
	System Influent	1415	8.5	-	210	390	-
	System Effluent	0845	8.7	57	3	60	<1.0
	System Effluent	1030	8.6	49	140	45	<1.0
	System Effluent	1230	8.6	47	290	35	<1.0
	System Effluent	1500	8.6	36	180	105	<1.0
	Background-Buoy	-	6.9	-	-	40	2×10^4
	Background-Dock	-	7.1	-	1	40	
3-27-71	System Influent	0830	7.0	-	340	470	
	System Influent	1030	8.3	-	730	650	
	System Influent	1300	7.0	-	310	220	
	System Influent	1430	7.1	-	650	500	
	System Effluent	0830	8.7	44	125	90	<1.0
	System Effluent	1030	8.7	11	280	55	5
	System Effluent	1300	8.3	10	385	20	$>1 \times 10^3$
	System Effluent	1430	8.0	14	435	30	2
	Background-Buoy	-	7.6	-	1	55	-

Location/Date	Sample Designation	Time	pH	ppm Residual Chlorine	BOD_5-ppm Total	Suspended Solids ppm	Coliform MPN col./100ml
3-28-71	System Influent	0830	7.0	-	140	420	-
	System Influent	1105	7.7	-	590	140	-
	System Influent	1320	7.4	-	1370	860	-
	System Influent	1430	7.4	-	330	240	-
	System Effluent	0830	8.5	31	205	280	<1.0
	System Effluent	1115	8.5	33	175	90	<1.0
	System Effluent	1345	8.6	48	195	50	<1.0
	System Effluent	1430	8.6	45	90	10	<1.0
3-29-71	System Influent	0850	7.0	-	230	40	-
	System Influent	1115	7.5	-	710	230	-
	System Influent	1430	8.0	-	350	200	-
	System Influent	1500	8.0	-	250	120	-
	System Effluent	0850	8.9	77	165	15	<1.0
	System Effluent	1125	8.9	106	180	15	<1.0
	System Effluent	1430	8.9	70	180	30	<1.0
	System Effluent	1500	8.8	67	165	15	<1.0
3-30-71	System Influent	0830	7.1	-	Depleted	1020	-
	System Influent	0930	7.0	-	Depleted	820	-
	System Influent	1315	7.9	-	Depleted	580	-
	System Influent	1435	7.3	-	290	90	-
	System Effluent	0900	8.5	35	88	10	OCL-15 mls/min.*
	System Effluent	0900	8.6	70	85	15	OCL-48 mls/min.
	System Effluent	0900	7.9	320	40	20	OCL-165 mls/min.
	System Effluent	0900	8.9	52	84	20	OCL-83 mls/min.
3-31-71	System Influent	0830	7.8	-	440	310	-
	System Influent	1040	8.4	-	230	320	-
	System Influent	1255	7.9	-	410	230	-
	System Effluent	1130	8.4	32	200	20	9
	System Effluent	1300	8.6	27	180	15	13
	System Effluent	1400	8.7	22	150	90	6

* Special BOD Test Using Additional Sodium Hypochlorite.

Location/Date	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	Suspended Solids ppm	Coliform MPN col./100ml
4-1-71	System Influent	0910	7.2	-	980	890	-
	System Influent	1100	8.5	-	760	510	-
	System Influent	1255	7.3	-	1250	640	-
	System Influent	1405	8.1	-	670	360	-
	System Effluent	0950	8.2	49	195	50	< 1.0
	System Effluent	1110	8.6	50	250	45	< 1.0
	System Effluent	1255	7.6	49	320	40	< 1.0
	System Effluent	1440	7.6	38	495	50	< 1.0
4-2-71	System Influent	0845	6.4	-	Depleted	1020	-
	System Influent	1115	7.5	-	230	190	-
	System Influent	1255	8.4	-	1370	750	-
	System Influent	1415	8.0	-	1420	1500	-
	System Effluent	1000	8.7	25	130	35	< 1.0
	System Effluent	1115	8.6	16	140	10	< 1.0
	System Effluent	1255	8.6	16	165	20	< 1.0
	System Effluent	1415	8.5	14	185	30	< 1.0
4-3-71	System Influent	-	7.5	-	280	180	-
	System Influent	-	8.2	-	590	600	-
	System Influent	-	7.1	-	1240	590	-
	System Influent	-	7.8	-	230	180	-
	System Effluent	-	8.8	46	155	15	< 1.0
	System Effluent	-	8.8	58	180	20	< 1.0
	System Effluent	-	8.7	60	330	25	< 1.0
	System Effluent	-	8.6	66	380	80	< 1.0
4-4-71	System Influent	0810	7.1	-	420	400	-
	System Influent	1050	7.2	-	180	230	-
	System Influent	1300	6.9	-	1400	560	-
	System Influent	1410	7.6	-	190	65	-
	System Effluent	1015	7.4	22	240	75	< 1.0
	System Effluent	1120	7.5	19	245	60	< 1.0
	System Effluent	1325	7.6	22	235	60	< 1.0
	System Effluent	1415	7.8	29	285	110	< 1.0

Location/Date	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	Suspended Solids ppm	Coliform MPN col./100ml
4-5-71	System Influent	0830	7.2	-	600	480	-
	System Influent	1030	6.8	-	650	580	-
	System Influent	1240	7.1	-	1320	750	-
	System Influent	1400	7.1	-	290	280	-
	System Effluent	0915	7.6	26	235	100	< 1.0
	System Effluent	1030	7.7	28	205	50	< 1.0
	System Effluent	1240	8.2	41	160	50	< 1.0
	System Effluent	1410	8.1	45	275	75	< 1.0
4-6-71	System Influent	0840	6.5	-	680	630	-
	System Influent	1015	3.8	-	230	250	-
	System Influent	1135	6.8	-	320	190	-
	System Influent	1340	8.9	-	780	620	-
	System Effluent	0840	7.6	24	195	40	7
	System Effluent	1020	7.9	39	290	60	6
	System Effluent	1135	8.3	117	255	50	< 1.0
	System Effluent	1340	8.4	170	245	135	< 1.0
4-7-71	System Influent	-	7.3	-	270	230	-
	System Influent	-	8.9	-	450	780	-
	System Influent	-	7.0	-	Depleted	940	-
	System Influent	-	7.2	-	470	295	-
	System Effluent	-	8.1	60	195	60	< 1.0
	System Effluent	-	8.0	55	190	60	< 1.0
	System Effluent	-	8.1	30	210	65	39
	System Effluent	-	8.2	30	255	60	900

Location/Date	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	Suspended Solids ppm	Coliform MPN col./100ml
4-8-71	System Influent	-	7.9	-	360	-	-
	System Influent	-	7.0	-	620	-	-
	System Influent	-	7.2	-	290	-	-
	System Influent	-	7.4	-	770	-	-
	System Effluent	-	8.8	0.5	195	-	-
	System Effluent	-	8.8	0.5	220	-	-
	System Effluent	-	8.9	58	185	-	-
	System Effluent	-	9.0	51	160	-	-
4-9-71	System Influent	-	6.6	-	-	-	-
	System Influent	-	9.4	-	-	-	-
	System Influent	-	7.3	-	-	-	-
	System Influent	-	7.3	-	-	-	-
	System Effluent	-	9.1	31	-	-	-
	System Effluent	-	9.2	16	-	-	-
	System Effluent	-	9.3	146	-	-	-
	System Effluent	-	9.3	136	-	-	-

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	BOD5-ppm Dissolved	Suspended Solids ppm	Coliform MPN col./100ml
BOCA GRANDE, FLORIDA								
4-16-71	System Influent	0915	-	-	975	60	1880	-
	Sample "A"	0935	-	-	59	48	900	-
	Sample "A"	1245	-	-	48	45	-	-
	Sample "B"	0945	-	-	-	-	1930	-
	Sample "C"	0930	-	-	59	-	-	-
	Sample "C"	1150	-	-	96	44	580	-
	Sample "D"	0945	-	-	-	-	19000	-
	Sample "E"	0950	-	-	78	70	470	-
	Sample "E"	1430	-	-	44	-	630	-
4-17-71	System Influent	0825	-	-	585	190	430	-
	System Influent	1000	-	-	270	85	1990	-
	System Influent	1110	-	-	350	190	2870	-
	System Influent	1235	-	-	1020	155	1660	-
	System Influent	1345	-	-	275	60	3660	-
	Sample "A"	0905	-	-	92	44	710	-
	Sample "A"	1345	-	-	50	46	1670	-
	Sample "B"	1345	-	-	46	42	3360	-
	Sample "C"	0830	-	-	72	-	-	-
	Sample "C"	1150	-	-	52	50	750	-
	Sample "C"	1340	-	-	72	65	-	-
	Sample "D"	-	-	-	-	-	15400	-
	Sample "E"	-	-	-	430	-	605	-
	Sample "E"	1145	-	-	74	-	470	-
	Sample "E"	1350	-	-	172	-	470	-

Key: Influent = Influent to system
"A" = Recycle/Effluent from sludge concentrator
"B" = Influent to sludge concentrator
C = Effluent from clarifier
D = Sludge Concentrator Effluent
"E" = System Effluent

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm		Suspended Solids ppm	Coliform MPN col./100ml
					Total	Dissolved		
4-19-71	System Influent	1100	-	-	336	319	705	-
	System Influent	1400	-	-	264	184	545	-
	System Influent	1440	-	-	762	546	4050	-
	System Influent	1645	-	-	406	76	150	-
	System Influent	1800	-	-	1668	606	100	-
	Sample "A"	1415	-	-	42	37	57	-
	Sample "A"	1800	-	-	43	42	72	-
	Sample "A"	2130	-	-	46	35	99	-
	Sample "B"	1415	-	-	45	40	680	-
	Sample "B"	1800	-	-	40	39	87	-
	Sample "C"	1430	-	-	39	-	17	-
	Sample "C"	1800	-	-	43	41	49	-
	Sample "D"	1800	-	-	-	-	5360	-
	Sample "E"	1800	-	-	41	39	160	-
	Sample "E"	2130	-	-	43	-	72	-
4-20-71	System Influent	0745	-	-	271	106	900	-
	System Influent	0745	-	-	340	256•	940	-
	Sample "A"	0930	-	-	43	26	250	-
	Sample "A"	1445	-	-	47	46	50	-
	Sample "B"	0930	-	-	38	24	45	-
	Sample "B"	1445	-	-	54	53	1900	-
	Sample "C"	1445	-	-	51	40	77	-
	Sample "D"	1000	-	-	-	-	10100	-
	Sample "E"	0825	-	-	92	-	30	-
	Sample "E"	1445	-	-	45	-	100	-
4-21-71	System Influent	1210	-	-	666	120	570	-
	System Influent	1400	-	-	214	84	500	-
	Sample "D"	1210	-	-	430	52	17670	-
	Sample "D"	1400	-	-	340	73	26020	-
	Sample "E"	1220	-	-	44	35	180	-
	System Effluent	1400	-	-	41	37	180	-

See Key page B-10

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm cal	BOD5-ppm Dissolved	Suspended Solids ppm	Coliform MPN col./100ml
4-22-71	System Influent	1000	-	-	706	373	1210	-
	System Influent	1330	-	-	956	585	3640	-
	Sample "A"	1335	-	-	34	33	1030	-
	Sample "B"	1335	-	-	32	31	2050	-
	Sample "C"	1330	-	-	34	-	435	-
	Sample "D"	1000	-	-	40	31	3580	-
	Sample "D"	1335	-	-	-	31	16210	-
	System Effluent	1000	-	-	29	27	74	-
	System Effluent	1330	-	-	35	34	280	-
SOUTHPORT, NORTH CAROLINA								
4-29-71	System Influent	1030	9.2	-	880	490	870	-
	System Influent	1330	8.1	-	1150	820	1600	-
	Sample "C"	1050	8.7	11	130	-	33	-
	Sample "C"	1400	8.7	35	130	-	15	-
	Sample "E"	1100	8.9	34	130	-	60	<1.0
	Sample "E"	1330	8.9	43	130	-	50	<1.0
	Background Water	-	8.3	-	0.3	-	40	1700
4-30-71	System Influent	1600	9.2	-	610	300	190	-
	System Influent	1915	8.6	-	250	200	230	-
	System Influent	2200	8.1	-	450	170	200	-
	Sample "C"	1615	8.6	13	130	-	44	-
	Sample "C"	1940	8.6	13	130	-	50	-
	Sample "C"	2135	8.4	11	130	120	84	-
	Sample "E"	1620	9.0	16	130	-	52	-
	Sample "E"	2200	8.7	11	130	-	13	-
	Sample "E"	0645	9.2	25	110	-	34	-
5-1-71	System Influent	1030	7.2	-	890	390	330	-
	System Influent	1622	7.9	-	260	100	200	-
	System Influent	1910	7.0	-	620	220	430	-
	Sample "E"	1045	8.9	10	110	-	14	-
	System Effluent	1630	9.0	9	300	-	38	-
	System Effluent	1920	8.7	7	220	-	20	-

See Key page B-10

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm		Suspended Solids ppm	Coliform MPN col./100ml
					Total	Dissolved		
5-2-71	System Influent	1300	7.9	-	450	220	250	-
	System Effluent	1430	9.0	47	215	-	150	-
5-7-71	System Influent	0600	7.8	-	500	150	-	-
	System Influent	1200	8.2	-	780	350	-	-
	System Effluent	0600	8.7	12	137	-	-	-
	System Effluent	1200	9.0	21	320	-	-	-
	Standard	-	-	-	200	-	-	-
5-10-71	System Influent	0630	8.2	-	380	185	270	-
	System Influent	1300	8.5	-	820	155	580	-
	System Influent	1800	5.6	-	1500	800	1300	-
	System Influent	2200	7.3	-	260	100	220	-
	System Effluent	0630	9.1	9	162	-	60	-
	System Effluent	1300	9.1	8	190	-	40	-
	System Effluent	1800	9.0	6	138	-	65	-
	System Effluent	2200	8.9	8	480	-	90	-
5-11-71	System Influent	0600	8.1	-	370	170	900	-
	System Influent	0930	6.8	-	1750	350	800	-
	System Influent	0600	8.8	7	450	-	44	-
	System Influent	0930	9.2	29	425	-	50	-
5-12-71	System Influent	1100	9.1	-	2000	800	1000	-
	System Influent	1745	5.5	-	1600	920	930	-
	System Influent	2000	7.9	-	640	260	330	-
	System Effluent	2000	9.1	20	210	-	70	-
	System Effluent	2200	9.0	20	225	-	30	-
5-16-71	System Influent	1015	8.5	-	670	-	470	-
	System Influent	1615	7.6	-	160	-	230	-
	System Influent	2030	9.0	-	190	-	280	-
	System Effluent	1420	9.0	30	245	-	18	-
	System Effluent	1830	8.7	20	135	-	74	-
	System Effluent	2220	8.8	22	132	-	50	-

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm		Suspended Solids ppm	Coliform MPN col./100ml
					Total	Dissolved		
5-17-71	System Influent	0630	6.8	-	760	-	570	-
	System Influent	1020	7.8	-	460	355	204	-
	System Influent	1730	5.3	-	1100	475	510	-
	System Influent	2100	7.5	-	680	-	290	-
	System Effluent	0630	8.9	31	154	-	33	-
	System Effluent	1330	9.3	21	330	-	64	-
	System Effluent	1950	9.5	16	315	-	63	-
	System Effluent	2200	9.6	8	270	-	75	-
5-24-71	System Influent	0820	8.7	-	540	240	680	-
	System Influent	1200	8.6	-	120	40	360	-
	System Effluent	1015	9.0	42	185	-	100	-
	System Effluent	1400	9.1	37	230	-	80	-
5-25-71	System Influent	0030	8.3	-	540	-	-	-
	System Influent	0800	7.0	-	1300	-	-	-
	System Influent	1330	9.5	-	520	-	-	-
	System Effluent	1000	9.2	34	310	-	-	-
	System Effluent	1330	9.2	15	425	-	-	-
	Standard	-	-	-	240	-	-	-
5-26-71	System Influent	0800	8.3	-	860	-	-	-
	System Influent	1200	7.3	-	600	-	-	-
	System Effluent	1000	9.0	68	340	-	-	-
	System Effluent	1400	9.1	42	340	-	-	-
6-20-71	System Influent	1145	7.4	-	300	-	-	-
	System Effluent	0850	9.0	$KmnO_4$	140	-	-	-
	System Effluent	1145	9.2	+ OCL	140	-	-	-
	System Effluent	1405	9.9	Exp.	160	-	-	-
6-21-71	System Influent	1225	6.7	-	220	-	-	-
	System Effluent	0830	8.8	$KmnO_4$	240	-	-	-
	System Effluent	1025	8.8	+	690	-	-	-
	System Effluent	1235	8.9	OCL	690	-	-	-
	System Effluent	1430	9.0	Exp.	680	-	-	-

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	BOD5-ppm Dissolved	Suspended Solids ppm	Coliform MPN col./100ml
6-22-71	System Influent	1220	9.2	-	290	-	-	-
	System Effluent	0800	8.8	KmnC$_4$	170	-	-	-
	System Effluent	1000	9.0	+	165	-	-	-
	System Effluent	1220	9.0	OCL	170	-	-	-
	System Effluent	1400	8.9	Exp.	220	-	-	-
6-25-71	System Influent	1330	8.6	-	880	-	-	-
	System Effluent	0800	9.4	14	140	-	-	-
	System Effluent	1345	9.6	51	210	-	-	-
6-26-71	System Influent	0845	7.1	-	400	-	-	-
	EC Cell Effluent	0848	7.1	-	420	-	-	-
	System Effluent	0800	8.9	15	155	-	-	-
	System Effluent	1000	8.9	20	150	-	-	-
	System Effluent	1400	8.9	17	160	-	-	-
7-9-71	System Influent	0830	7.8	-	1460	660	-	
	System Influent	1030	8.2	-	215	-	-	
	System Influent	1225	7.0	-	430	220	-	
	System Influent	1400	7.5	-	820	-	-	
	System Effluent	0800	8.7	-	260	-	-	
	System Effluent	1030	8.8	-	240	-	-	
	System Effluent	1225	9.5	102	220	-	-	
	System Effluent	1400	9.1	36	215	-	-	
7-10-71	System Influent	0800	9.4	-	235	-	-	
	System Influent	1000	8.2	-	770	340	-	
	System Influent	1200	8.7	-	300	-	-	
	System Effluent	0800	8.9	15	320	-	-	
	System Effluent	1000	9.5	75	285	-	-	
	System Effluent	1200	9.3	46	275	-	-	
7-14-71	System Influent	1100	8.6	-	420	-	1510	-
	Carbon Column Inf.	1310	9.3	28	230	-	34	-
	Effluent 2nd Col.	1315	7.6	5	46	-	14	-
	System Effluent	1415	7.6	5	47	-	20	-

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	BOD5-ppm Dissolved	Suspended Solids ppm	Coliform MPN col./100ml
7-15-71	System Influent	0830	7.9	-	500	-	1570	-
	Carbon Column Inf.	0900	9.2	20	160	-	27	-
	Effluent 2nd Col.	0900	8.4	-	80	-	11	-
	Effluent-System	0900	7.8	-	62	-	2	-
	Carbon Column Inf.	1300	9.3	25	280	-	43	-
	Effluent 2nd Col.	1300	8.6	10	82	-	21	-
	System Effluent	1300	8.1	-	60	-	20	-
7-16-71	System Influent	0810	7.8	-	380	-	1175	-
	Carbon Column Inf.	0830	9.1	25	150	-	41	-
	Carbon Column Inf.	1330	8.9	17	150	-	26	-
	Effluent 2nd Col.	0830	7.3	-	135	-	204	-
	Effluent 2nd Col.	1330	7.4	-	100	-	62	-
	System Effluent	0830	7.9	-	155	-	12	-
	System Effluent	1330	7.7	-	95	-	16	-
7-17-71	System Influent	0810	8.2	-	220	-	500	-
	Carbon Column Inf.	0830	9.2	26	120	-	26	-
	Carbon Column Inf.	1330	9.4	56	130	-	20	-
	Effluent 2nd Column	0850	7.5	-	90	-	55	-
	Effluent 2nd Column	1330	7.5	-	64	-	23	-
	System Effluent	0810	7.5	-	104	-	5	-
	System Effluent	1315	7.5	-	76	-	6	-
7-18-71	System Influent	0900	8.9	-	360	160	1020	-
	Carbon Column Inf.	0900	9.2	25	120	-	38	-
	Carbon Column Inf.	1300	9.3	35	205	-	54	-
	Effluent 2nd Column	0900	7.5	-	58	-	35	-
	Effluent 2nd Column	1300	7.5	-	94	-	70	-
	System Effluent	0900	7.5	-	70	-	17	-
	System Effluent	1300	7.5	-	74	-	24	-

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm		Suspended Solids ppm	Coliform MPN col./100ml
					Total	Dissolved		
7-19-71	System Influent	1300	8.7	-	400	120	580	-
	Carbon Column Inf.	1100	8.9	22	125	-	50	-
	Carbon Column Inf.	1400	9.3	44	170	-	66	-
	Effluent 2nd Column	1100	7.6	-	55	-	15	-
	Effluent 2nd Column	1400	7.8	-	58	-	50	-
	System Effluent	1400	7.7	-	46	-	28	-
7-20-71	System Influent	1015	8.8	-	600	160	1770	-
	Carbon Column Inf.	0800	9.0	8	130	-	45	-
	Carbon Column Inf.	1400	9.2	9	210	-	45	-
	Effluent 2nd Column	0800	7.8	-	56	-	47	-
	Effluent 2nd Column	1400	8.0	-	105	-	100	-
	System Effluent	0800	7.8	-	58	-	25	-
	System Effluent	0915	8.6	-	72	-	30	-
	System Effluent	1400	8.0	-	76	-	60	-
7-21-71	System Influent	0800	8.5	-	240	140	420	-
	Carbon Column Inf.	0800	9.6	37	105	-	24	-
	Effluent 2nd Column	0840	7.7	-	60	-	125	-
	System Effluent	0840	7.7	-	60	-	30	-
7-23-71	System Influent	1200	7.9	-	58-	330	580	-
	Carbon Column Inf.	0810	9.1	30	165	-	51	-
	Carbon Column Inf.	1330	9.0	25	200	-	36	-
	Effluent 2nd Column	0810	7.7	-	118	-	153	-
	Effluent 2nd Column	1330	8.1	-	90	-	102	-
	System Effluent	1330	8.0	-	100	-	58	-
	System Effluent	1430	7.9	-	118	-	144	-

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	BOD5-ppm Dissolved	Suspended Solids ppm	Coliform MPN col./100ml
7-26-71	System Influent	0815	4.4	-	340	170	460	-
	Carbon Column Inf.	0820	8.6	8	122	-	14	-
	Carbon Column Inf.	1300	8.8	14	115	-	40	-
	Carbon Column Inf.	1500	8.8	13	141	-	20	-
	Effluent 2nd Column	0820	7.8	-	62	-	190	-
	Effluent 2nd Column	1300	7.9	-	82	-	90	-
	Effluent 2nd Column	1500	7.9	-	82	-	90	-
	System Effluent	0820	7.4	-	42	-	40	-
	System Effluent	1300	7.4	-	49	-	95	-
	System Effluent	1500	-	-	89	-	60	-
7-27-71	System Influent	1100	8.8	-	720	440	640	-
	Carbon Column Inf.	0830	8.6	8	118	-	20	-
	Carbon Column Inf.	1230	9.2	38	215	-	76	-
	Carbon Column Inf.	1445	9.2	40	224	-	48	-
	Effluent 2nd Column	0830	7.9	-	68	-	90	-
	Effluent 2nd Column	1230	8.0	-	52	-	50	-
	Effluent 2nd Column	1445	8.3	-	88	-	42	-
	System Effluent	0830	7.3	-	32	-	45	-
	System Effluent	1230	7.4	-	32	-	18	-
	System Effluent	1445	7.4	-	68	-	44	-
7-28-71	System Influent	-	8.0	-	1400	90	490	-
7-29-71	System Influent	-	7.8	-	340	115	390	-
	Carbon Column Inf.	0830	8.5	8	99	-	87	-
	System Effluent	1345	9.0	75	66	-	75	
	Carbon Column Inf.	1345	7.6	-	54	-	57	-
	Effluent 2nd Column	0830	7.5	-	61	-	130	-
	Effluent 2nd Column	1345	7.9	-	59	-	78	-
	System Effluent	0830	8.5	-	66	-	59	-

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	BOD5-ppm Dissolved	Suspended Solids ppm	Coliform MPN col./100ml
7-30-71	System Influent	1240	7.9	-	330	80	230	-
	Carbon Column Inf.	0845	8.5	-	160	-	56	-
	Carbon Column Inf.	1400	8.5	-	230	-	53	-
	Effluent 2nd Column	0845	7.7	-	86	-	95	-
	Effluent 2nd Column	1400	7.8	-	125	-	110	-
	System Effluent	0845	8.5	-	105	-	40	-
	System Effluent	1400	8.8	-	110	-	66	-
7-31-71	System Influent	1130	7.0	-	1400	530	1240	-
	Carbon Column Inf.	0820	7.5	-	155	-	45	-
	Carbon Column Inf.	1310	7.7	-	130	-	100	-
	Effluent 2nd Column	0820	7.5	-	170	-	75	-
	Effluent 2nd Column	1310	7.6	-	110	-	50	-
	System Effluent	0820	9.0	-	180	-	36	-
	System Effluent	1310	8.8	-	150	-	23	-
8-1-71	System Influent	1245	9.0	-	250	-	290	-
	Carbon Column Inf.	0825	7.5	-	105	-	55	-
	Carbon Column Inf.	1400	8.3	-	230	-	95	-
	Effluent 2nd Column	0830	7.6	-	100	-	105	-
	Effluent 2nd Column	1400	7.6	-	170	-	65	-
	System Effluent	0845	8.5	-	135	-	60	-
	System Effluent	1400	8.7	-	130	-	50	-
8-2-71	System Influent	1405	7.7	-	840	280	460	-
	Carbon Column Inf.	0940	8.5	-	125	-	70	-
	Carbon Column Inf.	1410	8.5	-	230	-	70	-
	Effluent 2nd Column	0950	8.5	-	90	-	160	-
	Effluent 2nd Column	1410	8.5	-	204	-	175	-
	System Effluent	0950	8.3	-	150	-	205	-
	System Effluent	1415	8.8	-	150	-	105	-

Location/Dates	Sample Designation	Time	pH	ppm Residual Chlorine	BOD5-ppm Total	BOD5-ppm Dissolved	Suspended Solids ppm	Coliform MPN col./100ml
8-5-71	System Influent	1300	8.2	-	1200	540	-	-
	Carbon Column Inf.	1400	8.6	16	200	-	-	-
	Effluent 2nd Column	1400	7.8	-	140	-	-	-
	System Effluent	1400	8.8	29	200	-	-	-
8-7-71	System Influent	1215	7.8	-	1200	510	-	-
	Carbon Column Inf.	1130	8.5	13	190	-	-	-
	Carbon Column Inf.	1420	8.5	26	195	-	-	-
	Effluent 2nd Column	1130	8.3	-	200	-	-	-
	Effluent 2nd Column	1420	8.3	-	180	-	-	-
	System Effluent	1130	8.6	-	195	-	-	-
	System Effluent	1420	8.6	-	200	-	-	-
8-8-71	System Influent	1210	8.6	-	360	160	-	-
	Carbon Column Inf.	0820	8.8	22	130	-	-	-
	Carbon Column Inf.	1410	8.9	22	220	-	-	-
	Effluent 2nd Column	0820	8.2	-	43	-	-	-
	Effluent 2nd Column	1410	8.3	-	56	-	-	-
	System Effluent	0820	8.6	13	53	-	-	-
	System Effluent	1350	8.7	13	56	-	-	-
8-9-71	System Influent	1225	8.0	-	990	430	-	-
	Carbon Column Inf.	0835	8.7	15	115	-	-	-
	Carbon Column Inf.	1410	8.8	25	230	-	-	-
	Effluent 2nd Column	0835	8.2	-	45	-	-	-
	Effluent 2nd Column	1410	8.1	-	82	-	-	-
	System Effluent	0835	8.7	9	62	-	-	-
	System Effluent	1410	8.6	-	66	-	-	-

1 *Accession Number*

W

2 *Subject Field & Group*

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 *Organization*

General Electric, Re-entry and Environmental Systems Division
Philadelphia, Pennsylvania

6 *Title*

Watercraft Waste Treatment System
Development and Demonstration Report

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16 *Project Designation*

15020DHG

21 *Note*

22 *Citation*

23 *Descriptors (Starred First)*

25 *Identifiers (Starred First)*

27 *Abstract*

A demonstration program of electro-chemical processing of shipboard sanitary, culinary, and laundry wastes including prolonged sea trials on board a large vessel was conducted. Extensive analytical results are presented demonstrating ability to produce effluent of secondary water quality standard and to inciperate system by-products. Substantial data for the design of shipboard systems is also presented.

The economic viability of the treatment system developed is analyzed and compared with alternative approaches with the conclusion that dependence of large vessels on shore side facilities in conjunction with on-board holding equipment is eliminated in many cases.

The program demonstrates the unique character of shipboard wastes and the shipboard environment verifying the need for specially developed equipment for treatment such as the system demonstrated.

The program suggests further extension of the capabilities of the system developed for increase in capacity and for elimination of other ships wastes such as bilge water and wet and dry garbage.

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